

Snowmass**2013**

Community Planning Meeting aka CPM

High Energy Frontier

Michael Peskin (SLAC)

Chip Brock (MSU)

TOC:

1. High Energy Frontier, introduction
2. High Energy Frontier Study, practicalities
3. What's next for the High Energy Frontier
4. This Workshop

Snowmass is about: following the physics

and the route has just gotten a little clearer.

From 1967 to July

It's been a long 45 years



you never get tired of.



1967



Where Quality Starts Fresh Every Day



ELVIS
Indescribably Blue / Fools Fall in Love

VOLUME 19, NUMBER 21

PHYSICAL REVIEW LETTERS

20 NOVEMBER 1967

¹¹ In obtaining the expression (11) the mass difference between the charged and neutral has been ignored.
¹² M. Ademollo and R. Gatto, *Nuovo Cimento* **44A**, 282 (1966); see also J. Pasupathy and R. E. Marshak, *Phys. Rev. Letters* **17**, 888 (1966).
¹³ The predicted ratio [eq. (12)] from the current algebra

is slightly larger than that (0.23%) obtained from the ρ -dominance model of Ref. 2. This seems to be true also in the other case of the ratio $\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma) / \Gamma(\eta \rightarrow \gamma \gamma)$ calculated in Refs. 12 and 14.
¹⁴ L. M. Brown and P. Singer, *Phys. Rev. Letters* **8**, 460 (1962).

A MODEL OF LEPTONS*

Steven Weinberg†

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Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 17 October 1967)

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite¹ these spin-one bosons into a multiplet of gauge fields? Standing in the way of this synthesis are the obvious differences in the masses of the photon and intermediate meson, and in their couplings. We might hope to understand these differences by imagining that the symmetries relating the weak and electromagnetic interactions are exact symmetries of the Lagrangian but are broken by the vacuum. However, this raises the specter of unwanted massless Goldstone bosons.² This note will describe a model in which the symmetry between the electromagnetic and weak interactions is spontaneously broken, but in which the Goldstone bosons are avoided by introducing the photon and the intermediate-boson fields as gauge fields.³ The model may be renormalizable.

We will restrict our attention to symmetry groups that connect the *observed* electron-type leptons only with each other, i.e., not with muon-type leptons or other unobserved leptons or hadrons. The symmetries then act on a left-handed doublet

$$L = \begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad (1)$$

$$\mathcal{L} = -\frac{1}{2}(\partial_\mu \bar{A}_\nu - \partial_\nu \bar{A}_\mu + g \bar{A}_\mu \times \bar{A}_\nu)^2 - \frac{1}{2}(\partial_\mu B_\nu - \partial_\nu B_\mu)^2 - \bar{R} \gamma^\mu (\partial_\mu - ig' B_\mu) R - L \gamma^\mu (\partial_\mu - i g \bar{A}_\mu - i \frac{1}{2} g' B_\mu) L \\ - \frac{1}{2} \partial_\mu \varphi - ig \bar{A}_\mu \cdot \vec{T} \varphi + i \frac{1}{2} g' B_\mu \varphi^2 - G_e (\bar{L} \varphi R + \bar{R} \varphi^\dagger L) - M_1^2 \varphi^\dagger \varphi + h(\varphi^\dagger \varphi)^2. \quad (4)$$

We have chosen the phase of the R field to make G_e real, and can also adjust the phase of the L and Q fields to make the vacuum expectation value $\lambda = \langle \varphi^0 \rangle$ real. The "physical" φ fields are then φ^-

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and on a right-handed singlet

$$R = \begin{pmatrix} \frac{1}{2}(1 - \gamma_5) \nu_e \\ e \end{pmatrix}. \quad (2)$$

The largest group that leaves invariant the kinematic terms $-\bar{L} \gamma^\mu \partial_\mu L - \bar{R} \gamma^\mu \partial_\mu R$ of the Lagrangian consists of the electronic isospin \vec{T} acting on L , plus the numbers N_L , N_R of left- and right-handed electron-type leptons. As far as we know, two of these symmetries are entirely unbroken: the charge $Q = T_3 - N_R - \frac{1}{2} N_L$, and the electron number $N = N_R + N_L$. But the gauge field corresponding to an unbroken symmetry will have zero mass,⁴ and there is no massless particle coupled to N ,⁵ so we must form our gauge group out of the electronic isospin \vec{T} and the electronic hypercharge $Y = N_R + \frac{1}{2} N_L$.

Therefore, we shall construct our Lagrangian out of L and R , plus gauge fields \bar{A}_μ and B_μ coupled to \vec{T} and Y , plus a spin-zero doublet

$$\varphi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} \quad (3)$$

whose vacuum expectation value will break \vec{T} and Y and give the electron its mass. The only renormalizable Lagrangian which is invariant under \vec{T} and Y , plus a spin-zero doublet

PHYSICAL REVIEW LETTERS

20 NOVEMBER 1967

$$\varphi_3 = (\varphi^0 - \varphi^{0\dagger}) / i\sqrt{2}. \quad (5)$$

zero vacuum expectation value of perturbation theory, and therefore the φ_3 and φ^- have mass see that the Goldstone φ^- and φ^0 have no physical mass is gauge invariant combined isospin transformation which everywhere without changing the value of G_e is very large, φ^- is also disregarded

just to replace φ expectation value

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix}. \quad (6)$$

remain intact, while φ^- becomes

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix} + g' B_\mu \begin{pmatrix} 1 \\ 0 \end{pmatrix} - \lambda G_e \begin{pmatrix} 1 \\ 0 \end{pmatrix}. \quad (7)$$

$$\varphi_3 + \text{H.c.} + \frac{ig' \varphi_3}{(g^2 + g'^2)^{1/2}} \bar{\varphi}_3 \gamma^\mu e A_\mu + \frac{i(g^2 + g'^2)^{1/2}}{4} \left[\left(\frac{3g'^2 - g^2}{g^2 + g'^2} \right) \bar{\varphi}_3 \gamma^\mu e - \bar{\varphi}_3 \gamma^\mu \gamma_5 e + \bar{\varphi}_3 \gamma^\mu (1 + \gamma_5) \nu \right] Z_\mu. \quad (14)$$

electric charge

$$g'^2)^{1/2} \quad (15)$$

couple as usual to hadronic coupling constant

$$g'^2 = 1/2\lambda^2. \quad (16)$$

coupling constant is

$$g'^2 = 2.07 \times 10^{-6}.$$

is stronger by a very weak. Note also larger than e , so $\sim 10^6$ BeV, while (12) gives $\sim 10^6$ BeV predictions made

We see immediately that the electron mass is λG_e . The charged spin-1 field is

$$W_\mu = 2^{-1/2} (A_\mu^1 + i A_\mu^2) \quad (8)$$

and has mass

$$M_W = \frac{1}{2} \lambda g. \quad (9)$$

The neutral spin-1 fields of definite mass are

$$Z_\mu = (g^2 + g'^2)^{-1/2} (g A_\mu^3 + g' B_\mu), \quad (10)$$

$$A_\mu = (g^2 + g'^2)^{-1/2} (-g' A_\mu^3 + g B_\mu). \quad (11)$$

Their masses are

$$M_Z = \frac{1}{2} \lambda (g^2 + g'^2)^{1/2}, \quad (12)$$

$$M_A = 0, \quad (13)$$

so A_μ is to be identified as the photon field. The interaction between leptons and spin-1 mesons is

by this model have to do with the couplings of the neutral intermediate meson Z_μ . If Z_μ does not couple to hadrons then the best place to look for effects of Z_μ is in electron-neutron scattering. Applying a Fierz transformation to the W -exchange terms, the total effective $e-\nu$ interaction is

$$\frac{G_W}{\sqrt{2}} \bar{\nu} \gamma_\mu (1 + \gamma_5) \nu \left\{ \frac{(3g^2 - g'^2)}{2(g^2 + g'^2)} \bar{e} \gamma^\mu e + \frac{1}{2} \bar{e} \gamma^\mu \gamma_5 e \right\}.$$

If $g \gg e$ then $g \gg g'$, and this is just the usual $e-\nu$ scattering matrix element times an extra factor $\frac{1}{2}$. If $g \sim e$ then $g \sim g'$, and the vector interaction is multiplied by a factor $-\frac{1}{2}$ rather than $\frac{1}{2}$. Of course our model has too many arbitrary features for these predictions to be

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Z. Physik **88**, 161 (1934). A model similar to ours is discussed by S. Glashow, *Nucl. Phys.* **22**, 579 (1961); the chief difference is that Glashow introduces symmetry-breaking terms into the Lagrangian, and therefore gets less definite predictions.
J. Goldstone, *Nuovo Cimento* **19**, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, *Phys. Rev.* **127**, 965 (1962).
P. W. Higgs, *Phys. Letters* **12**, 132 (1964), *Phys. Rev. Letters* **13**, 508 (1964), and *Phys. Rev.* **145**, 1156 (1966); F. Englert and R. Brout, *Phys. Rev. Letters* **17**, 321 (1966); G. S. Guralnik, C. R. Hagen, and T. W. Kibble, *Phys. Rev. Letters* **13**, 585 (1964).
See particularly T. W. B. Kibble, *Phys. Rev.* **155**, 84 (1967). A similar phenomenon occurs in the strong interactions; the ρ -meson mass in zeroth-order perturbation theory is just the bare mass, while the meson picks up an extra contribution from the spontaneous breaking of chiral symmetry. See S. Weinberg, *Phys. Rev. Letters* **18**, 507 (1967), especially footnote J. Schwinger, *Phys. Letters* **24B**, 473 (1967); Glashow, H. Schnitzer, and S. Weinberg, *Phys. Rev. Letters* **19**, 139 (1967), Eq. (13) *et seq.*
T. D. Lee and C. N. Yang, *Phys. Rev.* **95**, 101 (1955). This is the same sort of transformation as that which eliminates the nonderivative \vec{T} couplings in the model; see S. Weinberg, *Phys. Rev. Letters* **18**, 188 (1967). The \vec{T} reappears with derivative coupling because the strong-interaction Lagrangian is not invariant under chiral gauge transformation.
For a similar argument applied to the σ meson, see Weinberg, Ref. 6.
R. P. Feynman and M. Gell-Mann, *Phys. Rev.* **169**, 1 (1957).

MIXING, AND LEPTON-PAIR MESONS*

J. Upton, New York

and the Department of Physics,
Chicago, Illinois
(Received 19 October 1967)

the current-mixing model is shown
in Weinberg's first sum rule as applied
to among the leptonic decay rates of ρ^0 ,
are discussed.

extended to the $(1+8)$ vector currents of the

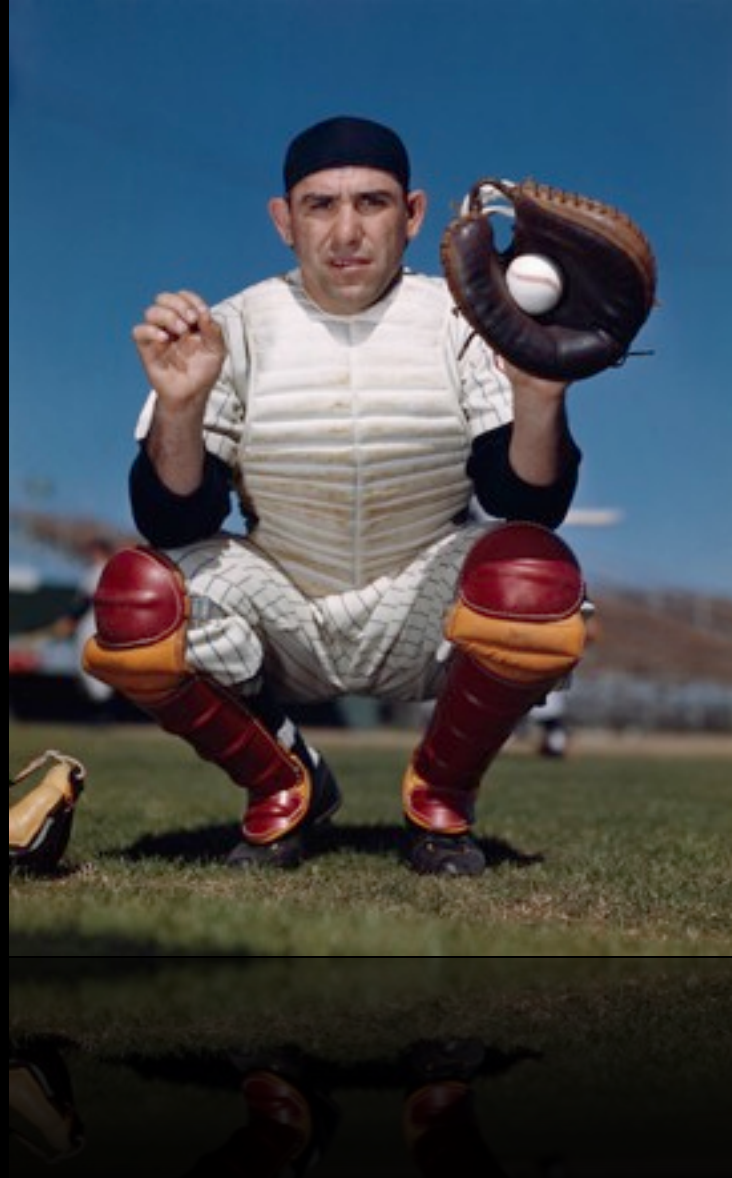
$$|1\rangle = S^0_{\alpha\beta} + S'^0_{\alpha\beta} \delta_{\beta 0}, \quad (1)$$

1967



Where Quality Starts Fresh Every Day

Peskin/Brock



“Ninety percent of this game is
half mental.

The most precise theory in the history of physics

Quantity	Value	Standard Model	Pull	Dev.
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1	0.0
Γ_Z [GeV]	2.4952 ± 0.0023	2.4961 ± 0.0010	-0.4	-0.2
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7426 ± 0.0010	—	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.69 ± 0.06	—	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	84.005 ± 0.015	—	—
σ_{had} [nb]	41.541 ± 0.037	41.477 ± 0.009	1.7	1.7
R_e	20.804 ± 0.050	20.744 ± 0.011	1.2	1.3
R_μ	20.785 ± 0.033	20.744 ± 0.011	1.2	1.3
R_τ	20.764 ± 0.045	20.789 ± 0.011	-0.6	-0.5
R_b	0.21629 ± 0.00066	0.21576 ± 0.00004	0.8	0.8
R_c	0.1721 ± 0.0030	0.17227 ± 0.00004	-0.1	-0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.0143 ± 0.00021	-0.7	-0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.4	0.6
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5	1.6
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1000 ± 0.0007	-2.6	-2.3
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0700 ± 0.0005	-0.9	-0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.010	0.0970 ± 0.0007		
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0008			
	0.23200 ± 0.0001			
	0.2287 ± 0.0001			
A_e	0.15138 ± 0.0001			
	0.1544 ± 0.0006			
	0.1498 ± 0.0004		0.5	0.6
A_μ	0.142 ± 0.015		-0.4	-0.3
A_τ	0.136 ± 0.015		-0.8	-0.7
	0.1439 ± 0.0043		-0.8	-0.7
A_b	0.923 ± 0.020	0.9348 ± 0.0001	-0.6	-0.6
A_c	0.670 ± 0.027	0.6680 ± 0.0004	0.1	0.1
A_s	0.895 ± 0.091	0.9357 ± 0.0001	-0.4	-0.4

Quantity	Value	Standard Model	Pull	Dev.
m_t [GeV]	173.4 ± 1.0	173.5 ± 1.0	-0.1	-0.3
M_W [GeV]	80.420 ± 0.031	80.381 ± 0.014	1.2	1.6
	80.376 ± 0.033		-0.2	0.2
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0398 ± 0.0003	0.0	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0	0.0
$Q_W(e)$	-0.0403 ± 0.0053	-0.0474 ± 0.0005	1.3	1.3
$Q_W(\text{Cs})$	-73.20 ± 0.35	-73.23 ± 0.02	0.1	0.1
$Q_W(\text{Tl})$	-116.4 ± 3.6	-116.88 ± 0.03	0.1	0.1
τ_τ [fs]	291.13 ± 0.43	290.75 ± 2.51	0.1	0.1
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	$(4511.07 \pm 0.77) \times 10^{-9}$	$(4508.70 \pm 0.09) \times 10^{-9}$	3.0	3.0

J. Beringer *et al.*(PDG), PR D86, 010001 (2012) (<http://pdg.lbl.gov>)



Standard

Model

standard /'stændərd/

noun

1. a level of quality or attainment

model /'mɒdl/

noun

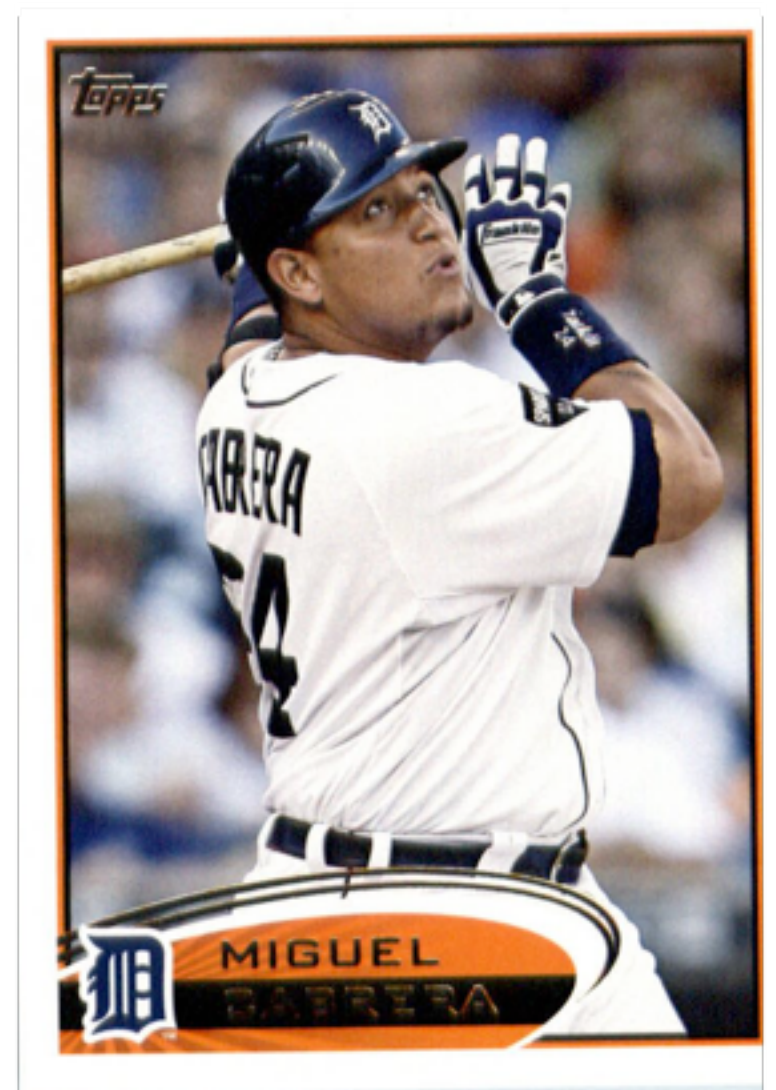
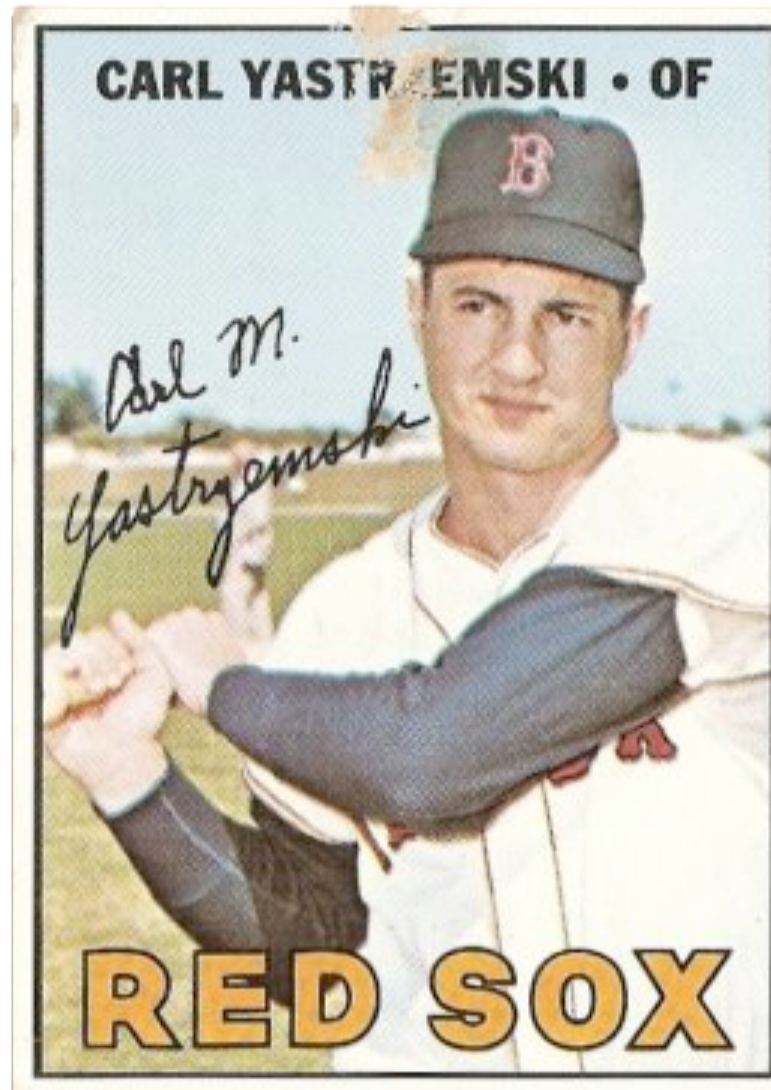
2. a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predictions

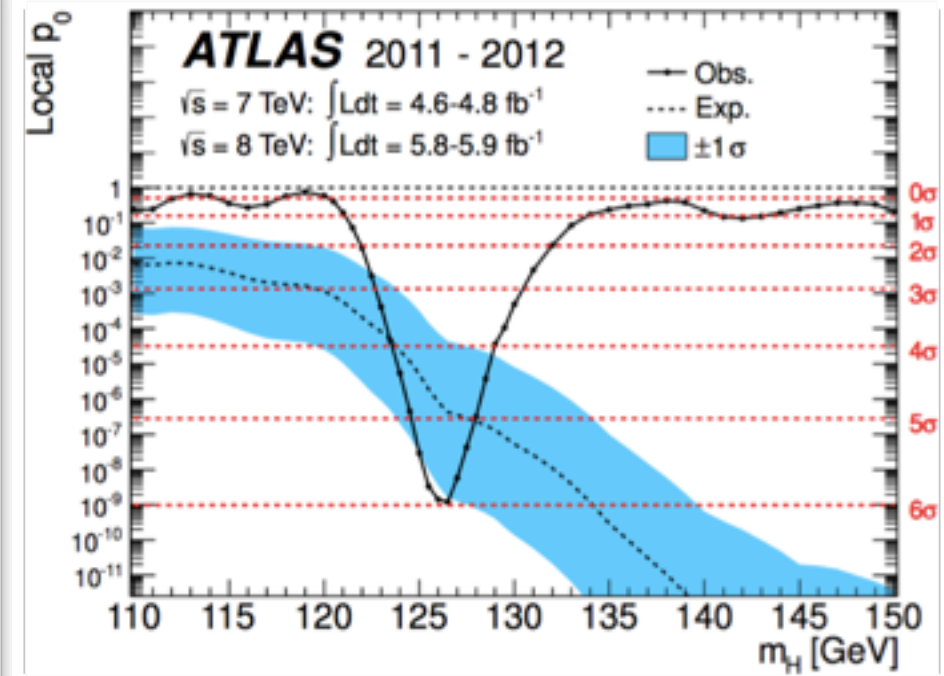
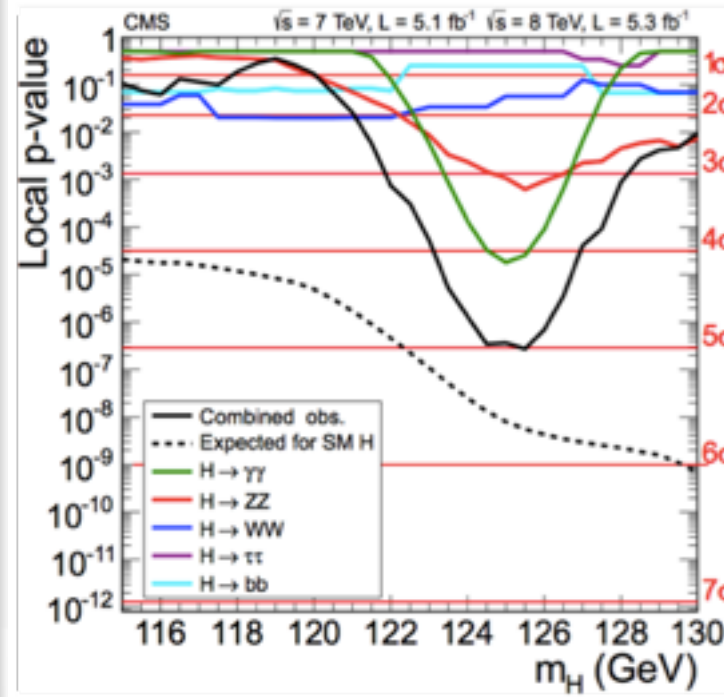
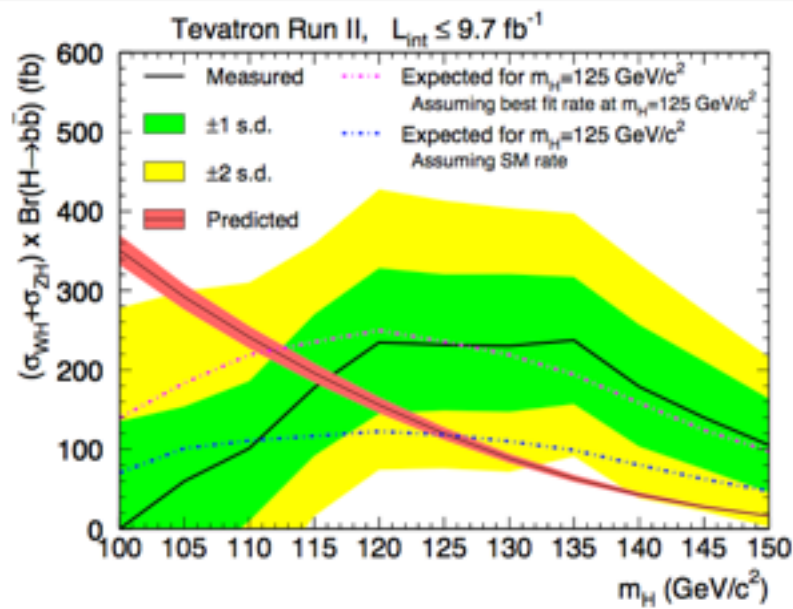
1967 - 2012

history was made

1967 - 2012

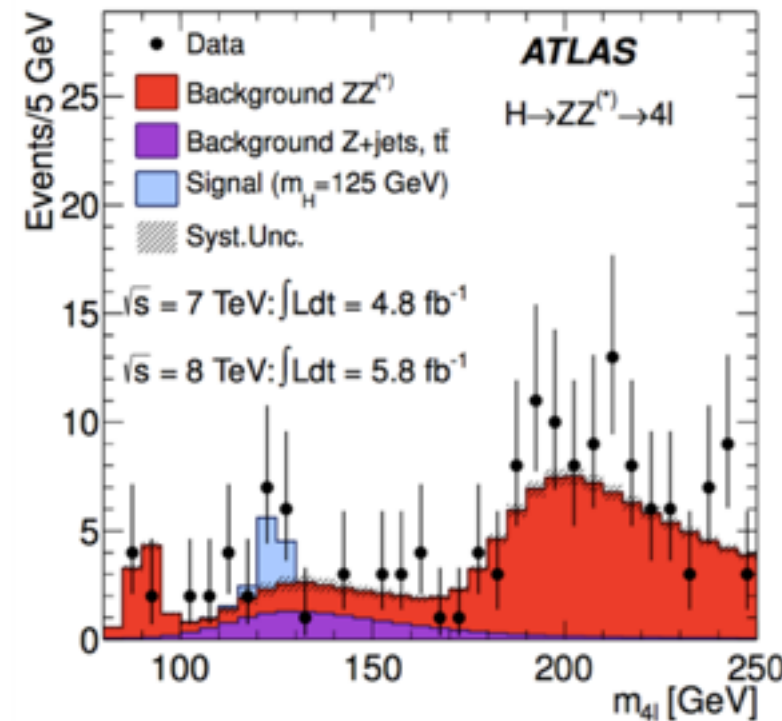
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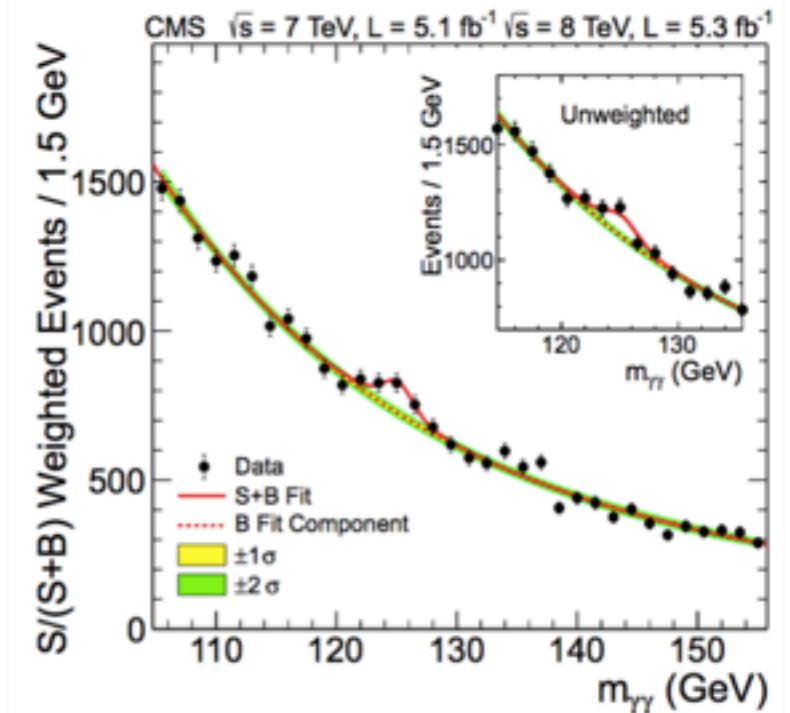


1967 - 2012

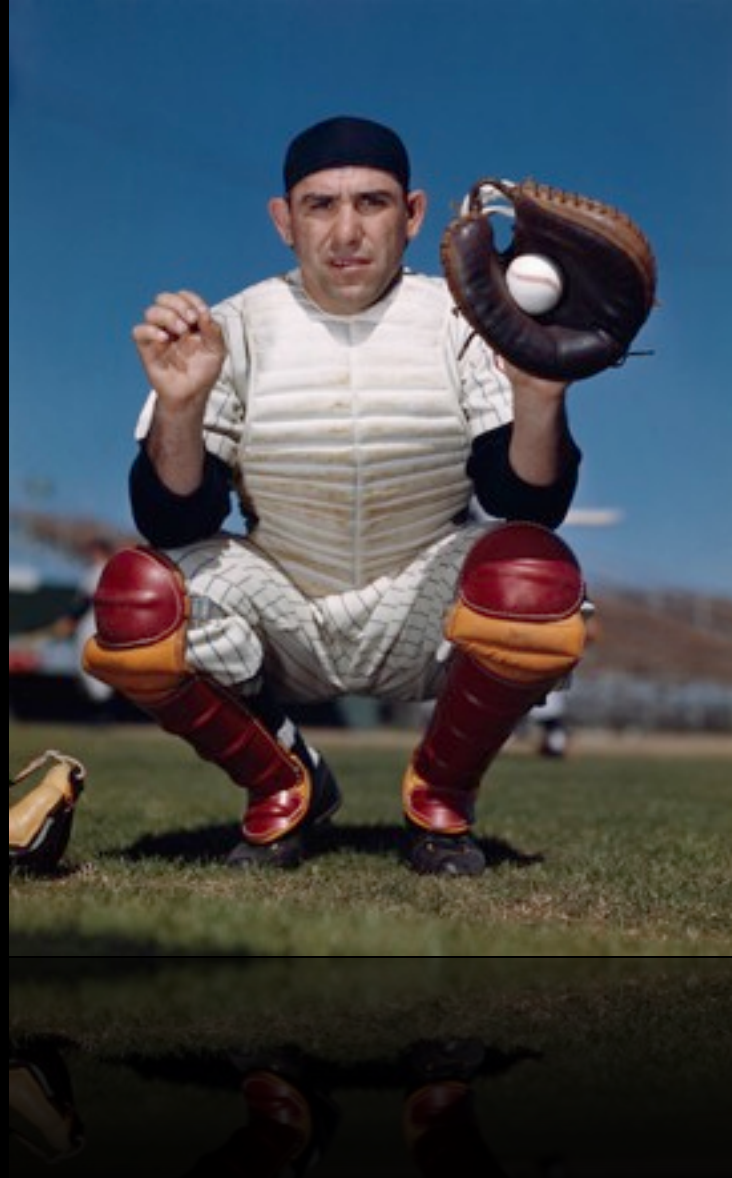
history was made



arXiv:1207.7214v1 [hep-ex]



arXiv:1207.7235v1 [hep-ex]



“I always thought that record would stand until it was broken.”



Standard Model

**tempting to think that the
puzzle is solved**



But we know better

The High Energy Frontier has 4 jobs:

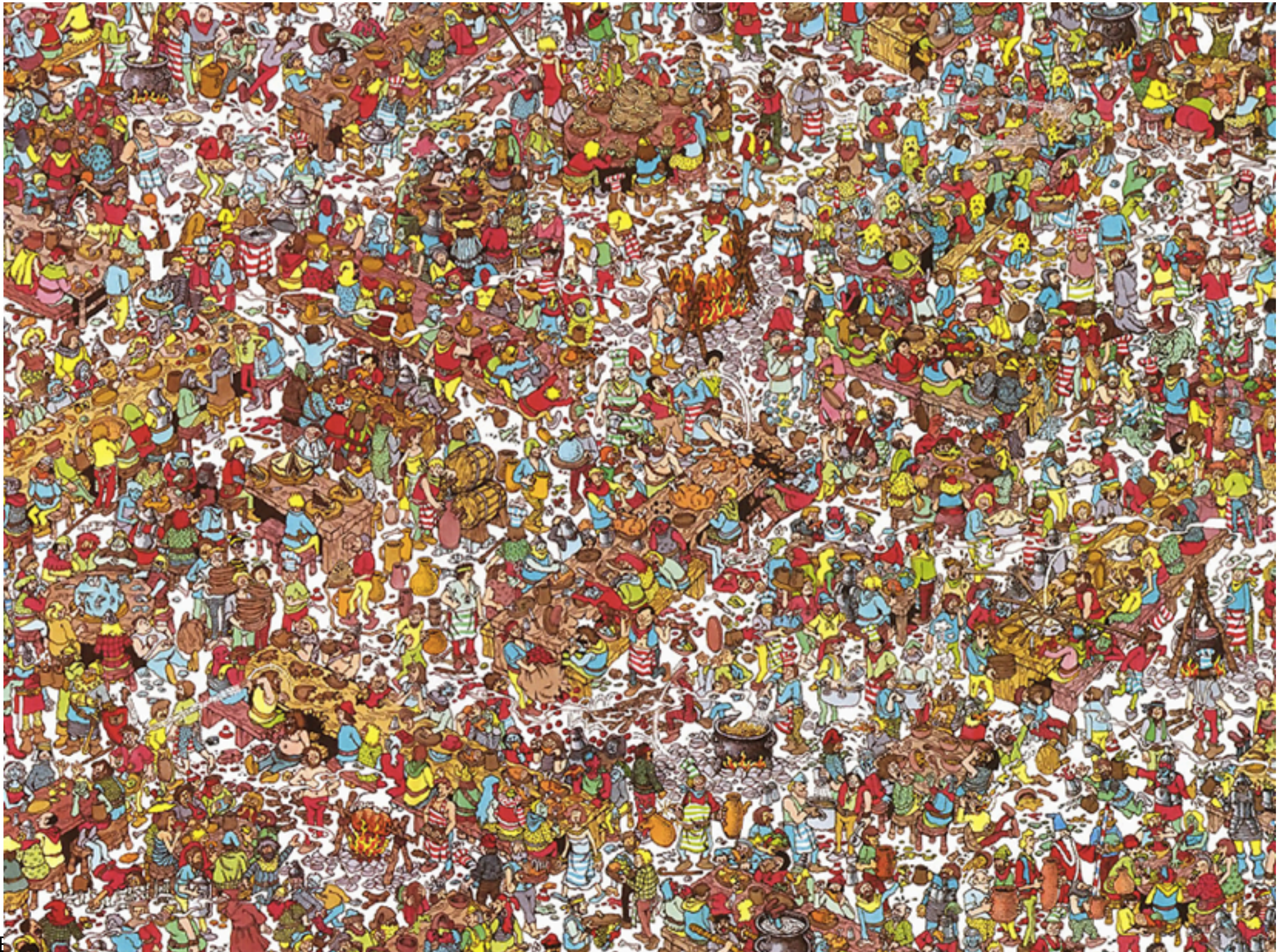
- Job 1.** *follow the obvious experimental imperative*
- Job 2.** *unravel some confusions*
- Job 3.** *complete a story*
- Job 4.** *remember history*

Job 1

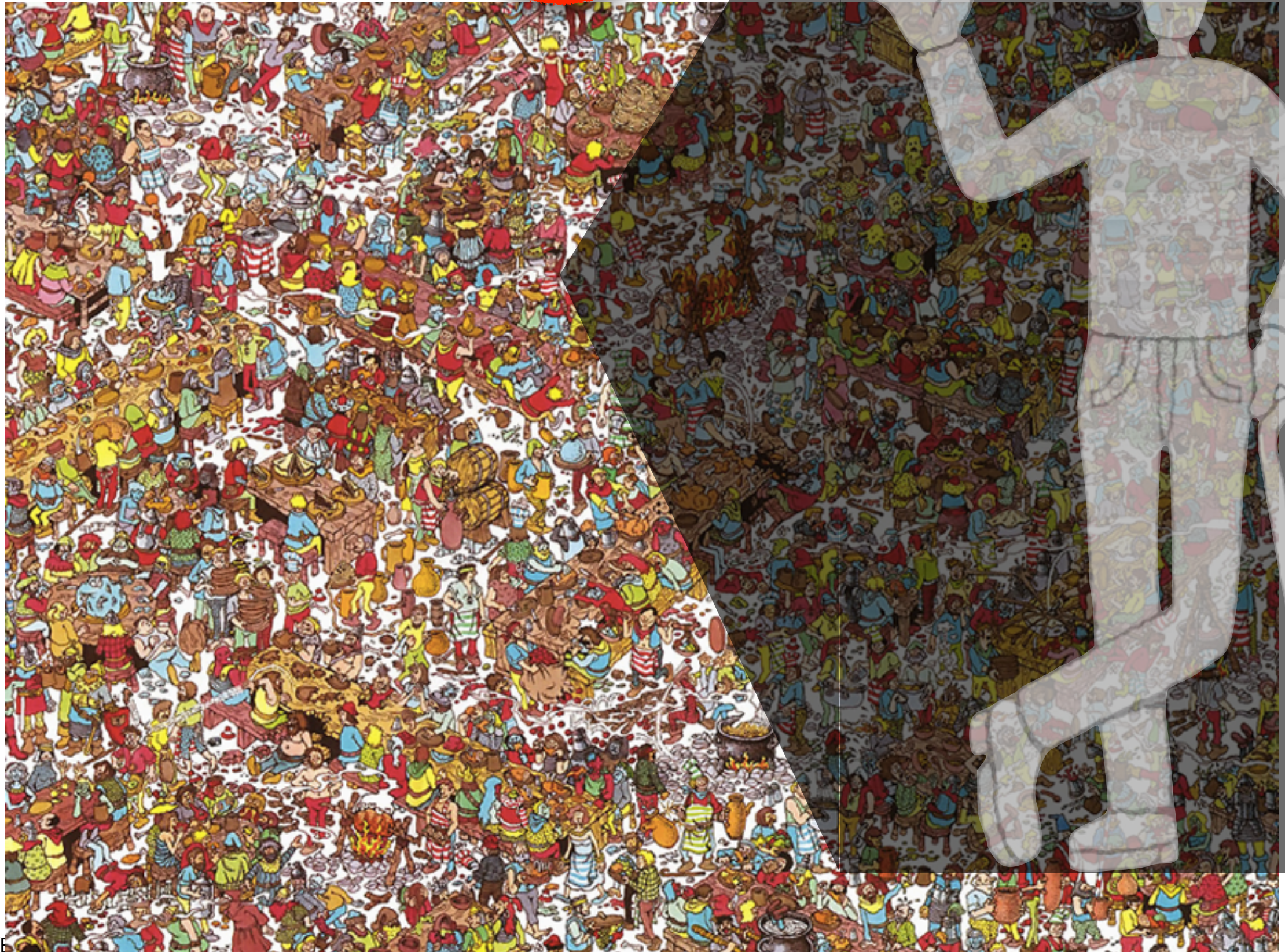
what just happened?



the Object Itself

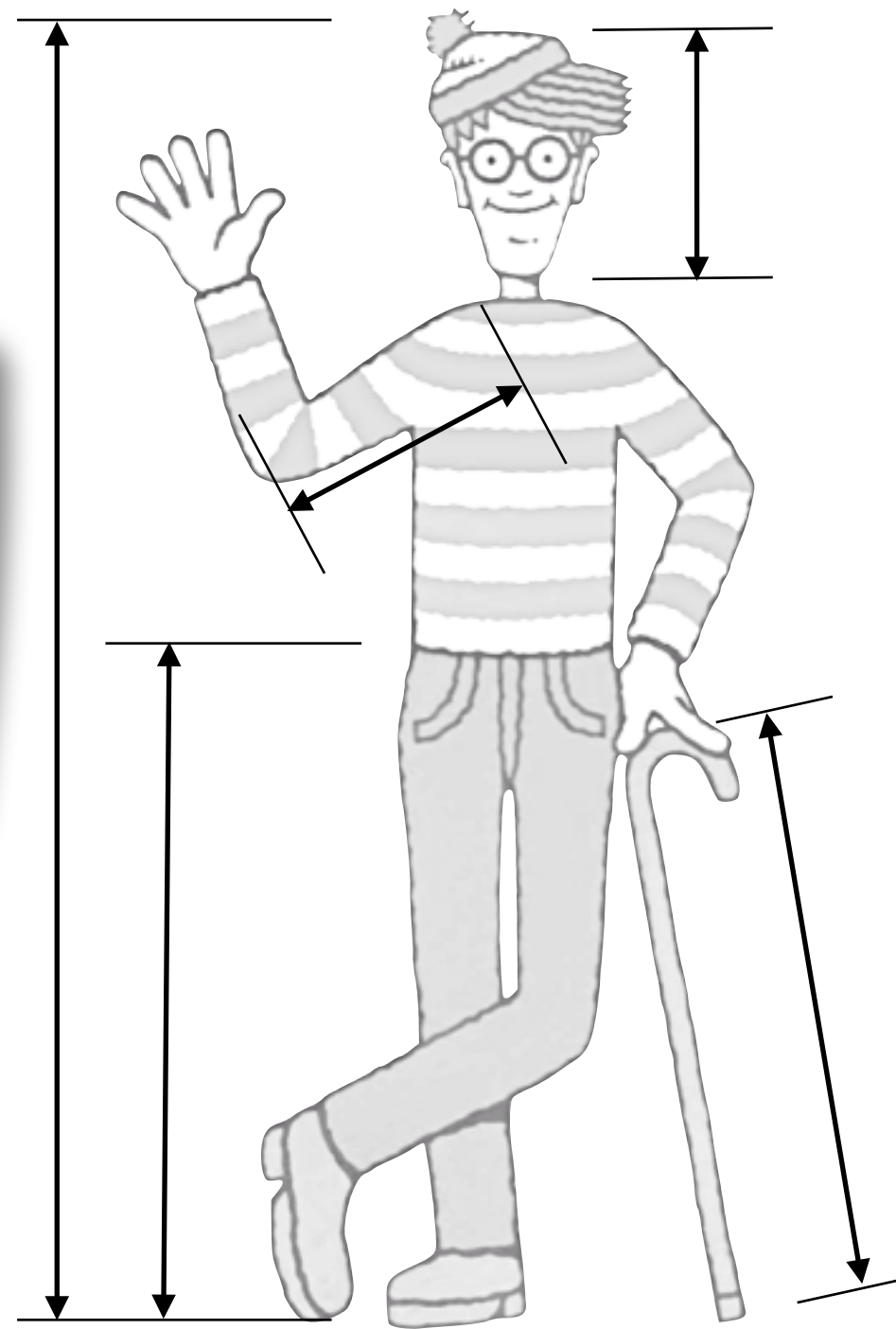


the Object Itself? It's...hazy



what's next with the Higgs-like-object?

HEF job: measure
it... exhaustively



we have to measure:

mass

spin and parity (J^P) looks like J^P $0^{+,-}$?... $2^{+,-}$? mixture?

couplings to vector bosons critical

all of the couplings to fermions, esp top and tau and b

couplings proportional to mass??

all branching fractions

singlet? how many are there?

elementary?

mixing with hidden sectors?

self-interactions?



Job 2

we have hair-on-fire observational
~~*problems, disasters, conundrums,*~~
...challenges.



First, the Higgs is too light



the same field theory

that in loops predicted the top mass range

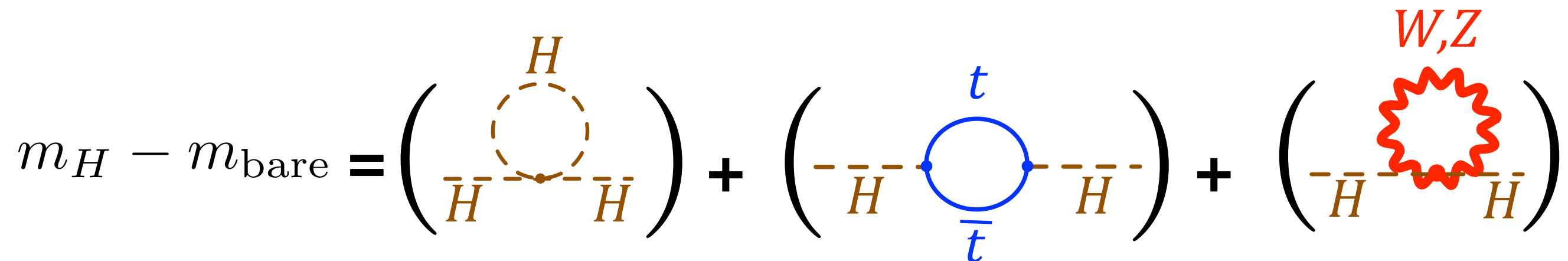
and now in loops the Higgs mass range

*leads us to ~~trouble~~ **opportunity***

something has to protect the mass

quadratic divergences..."naturalness problem"

better: the "Naturalness Hint"

$$m_H - m_{\text{bare}} = \left(\text{Higgs self-energy loop} \right) + \left(\text{top quark loop} \right) + \left(\text{W/Z loop} \right)$$


Taming this requires New Physics:

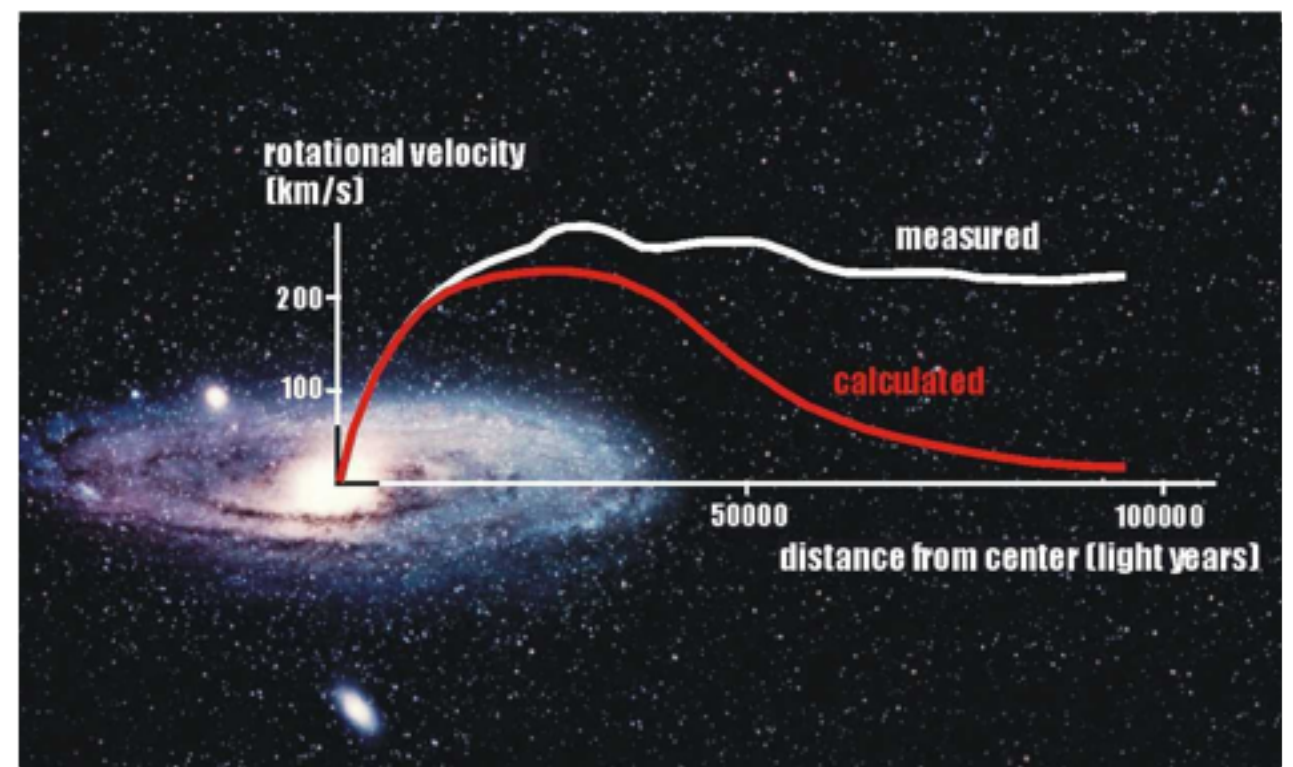
a symmetry? compositeness?

HEF job: unravel it

Second, galaxies move in ways that they shouldn't

Not like Newton

Andromeda





DARK MATTER

since Nature's clumpy

there has to be a Dark Matter quantum



HEF job: find it

Third, where is all of the antimatter?



Third, where is all of the antimatter?

Some new force?

HEF job: find evidence

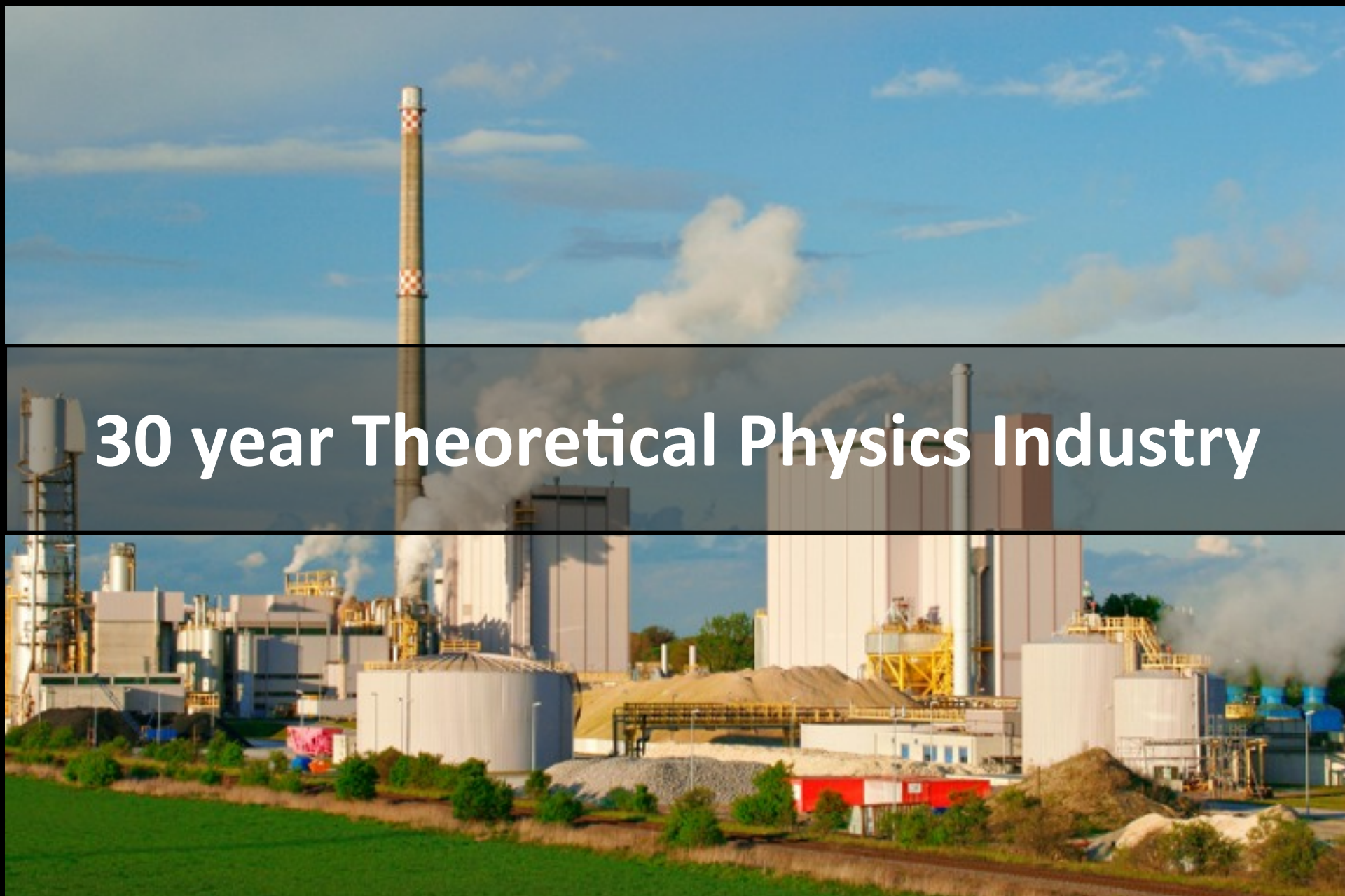




**something
beyond
the SM!**



“Beyond the Standard Model”*



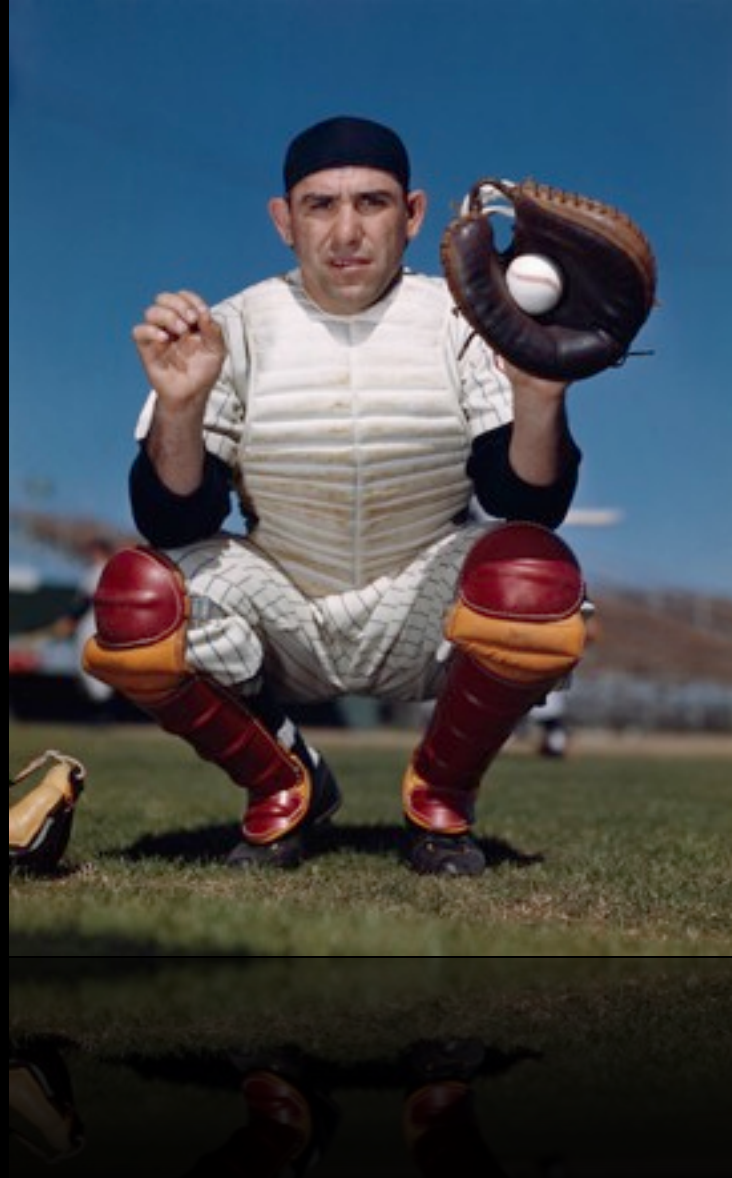
* Mr Google says: 49,900,000 hits.



Beyond the Standard Model



* Mr Google says: 49,900,000 hits.



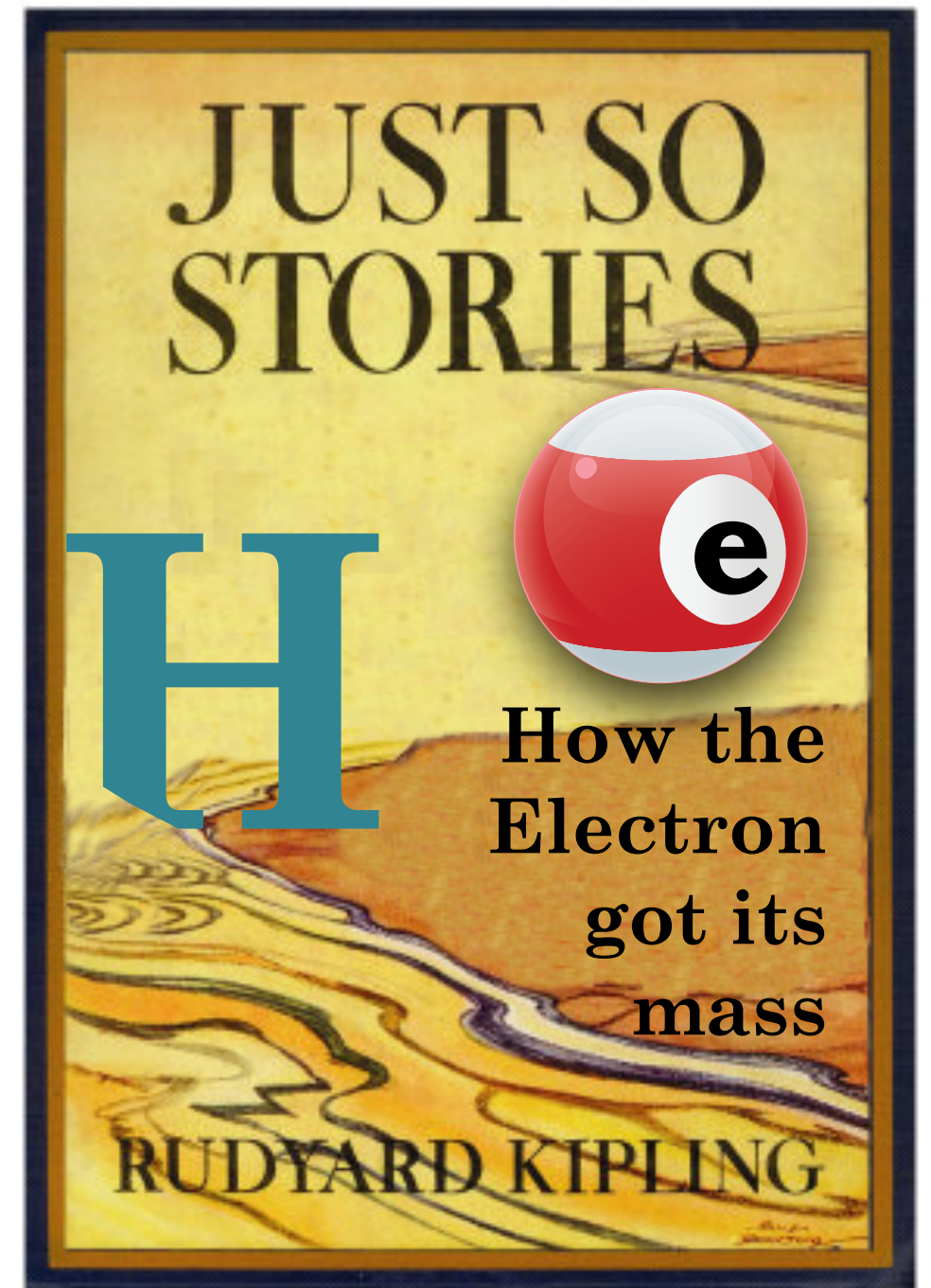
“I never said most of the things I said.”

Job 3

we have a story to tell

The Standard Model didn't have to unfold so...nicely

We don't know the characters, the plot is still developing, but the storyline is gripping.

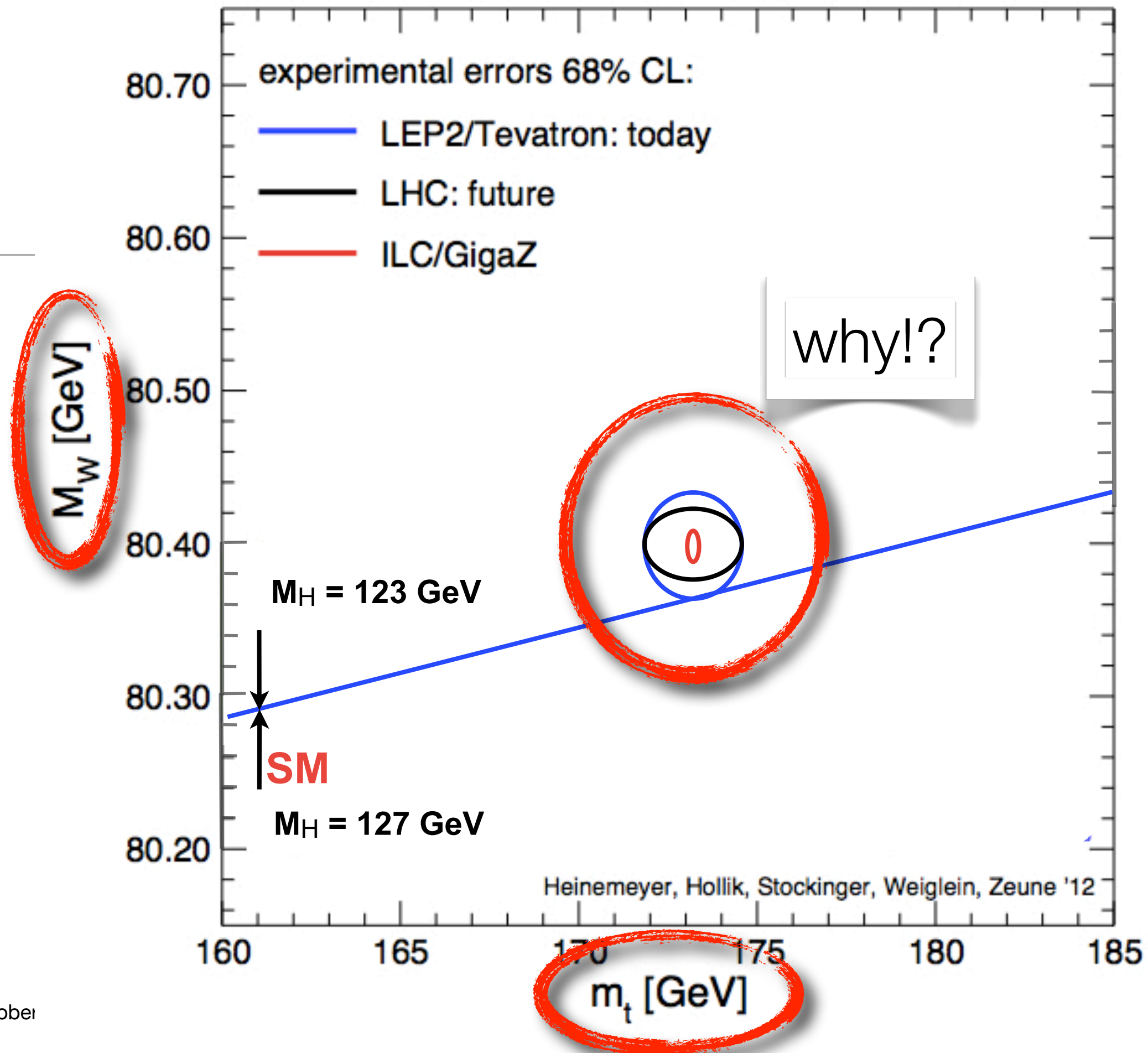


the story:

decades of
work
constrained
the Higgs

to exactly the
right place?

or *nearly* the
right place?

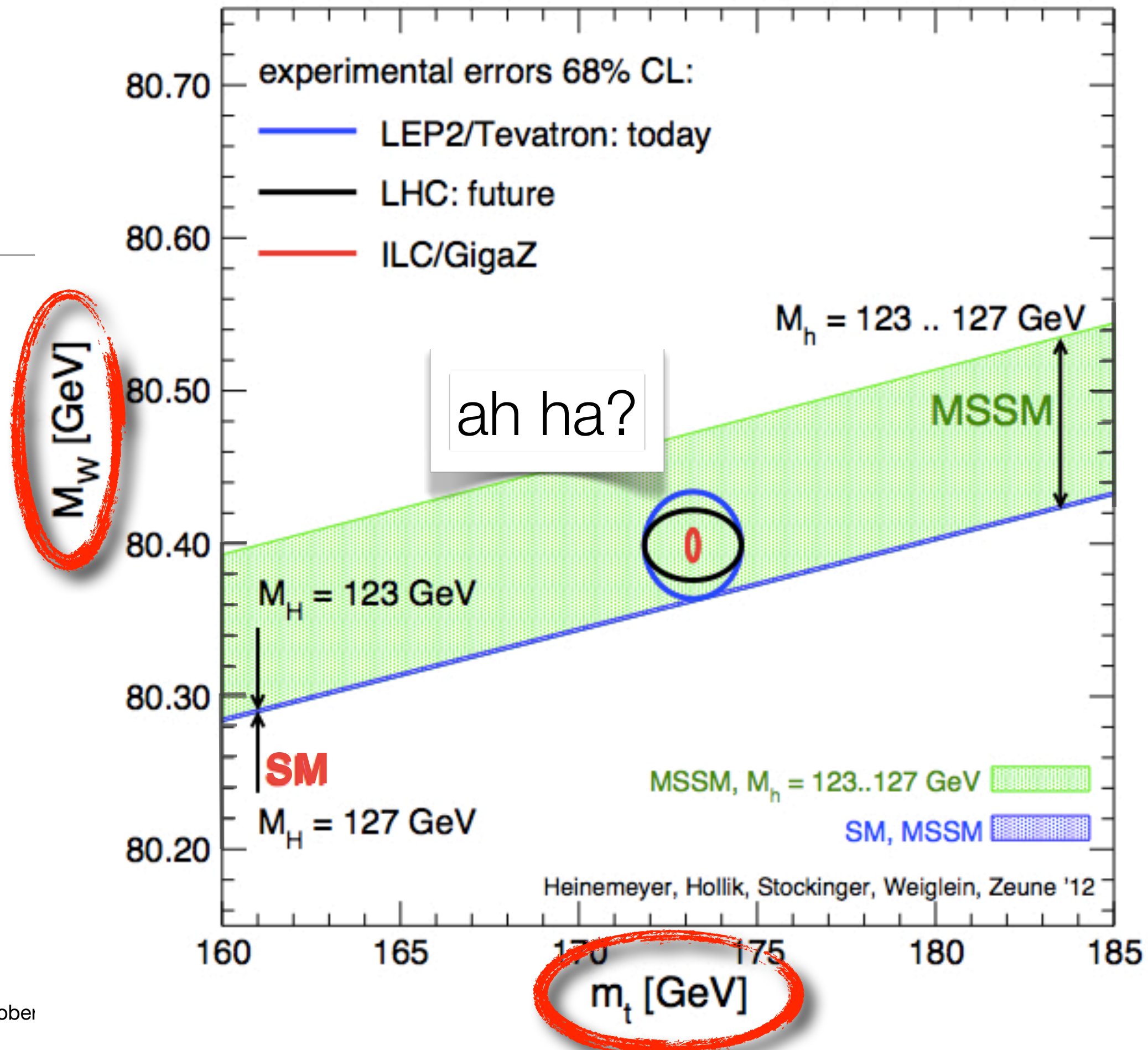


the story:

decades of
work
constrained
the Higgs

to exactly the
right place?

or *nearly* the
right place?



SM requires correlations among measurables

inconsistencies have to show up



HEF job: find them

Job 4

**things don't always follow
a roadmap!**

remember the:

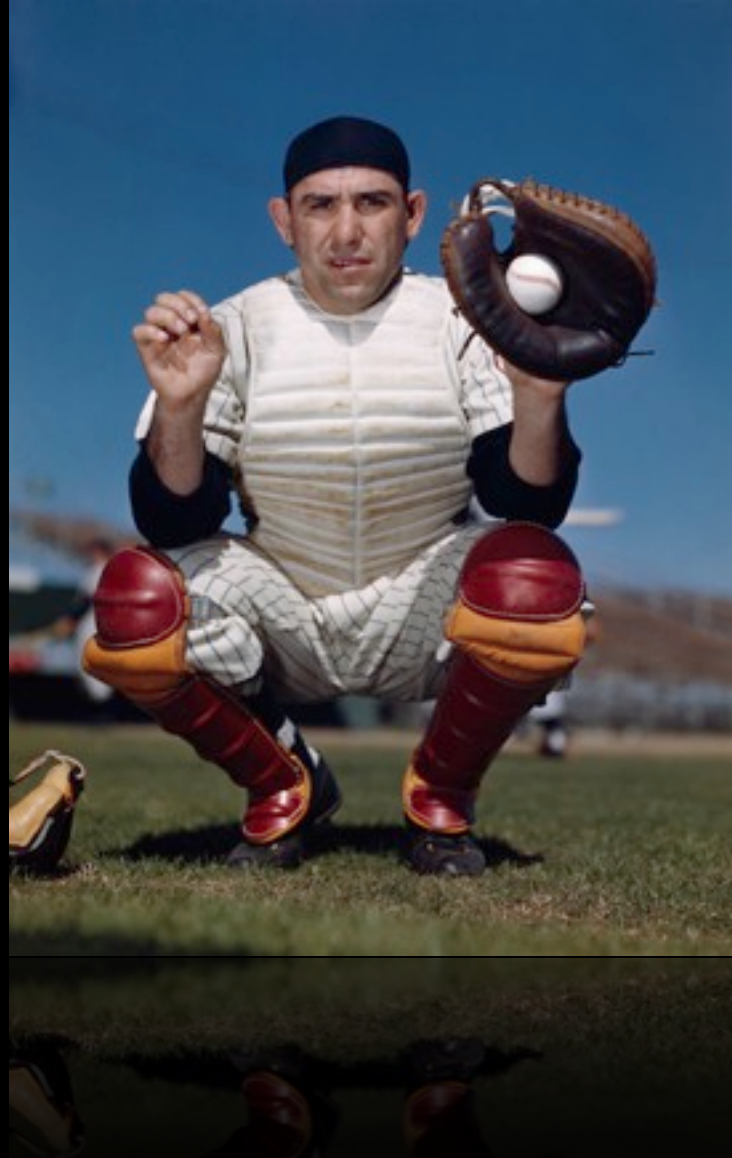
B lifetime

muon

Charm

etc





“You've got to be very careful if you
don't know where you are going
because you might not get there.

Precision is the tool

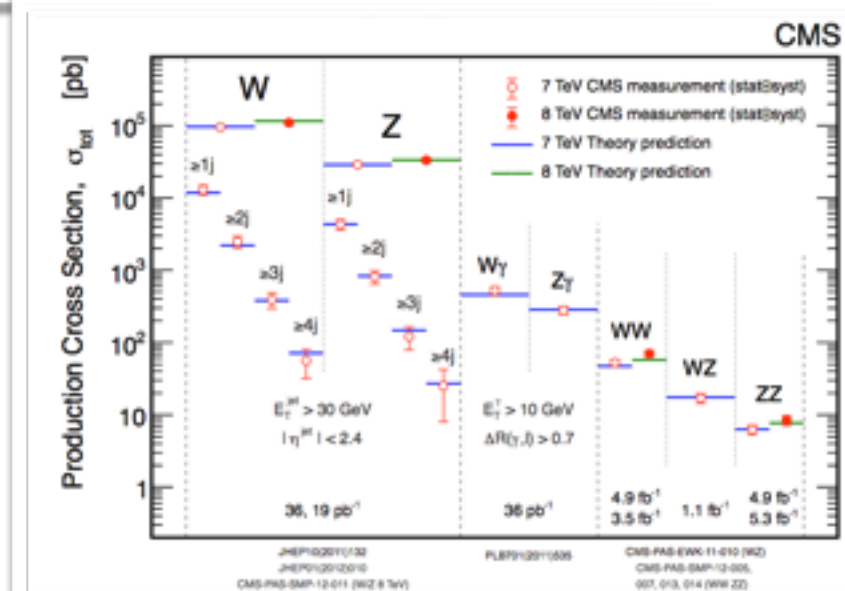
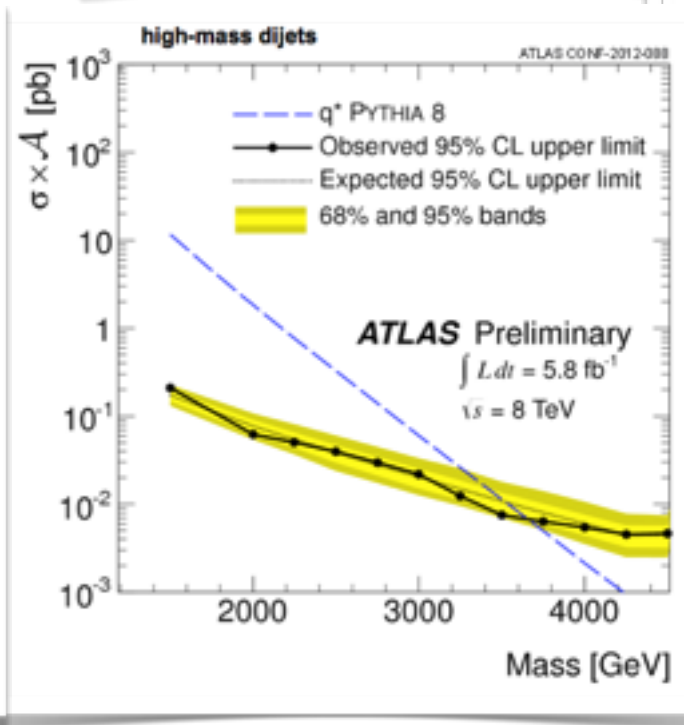
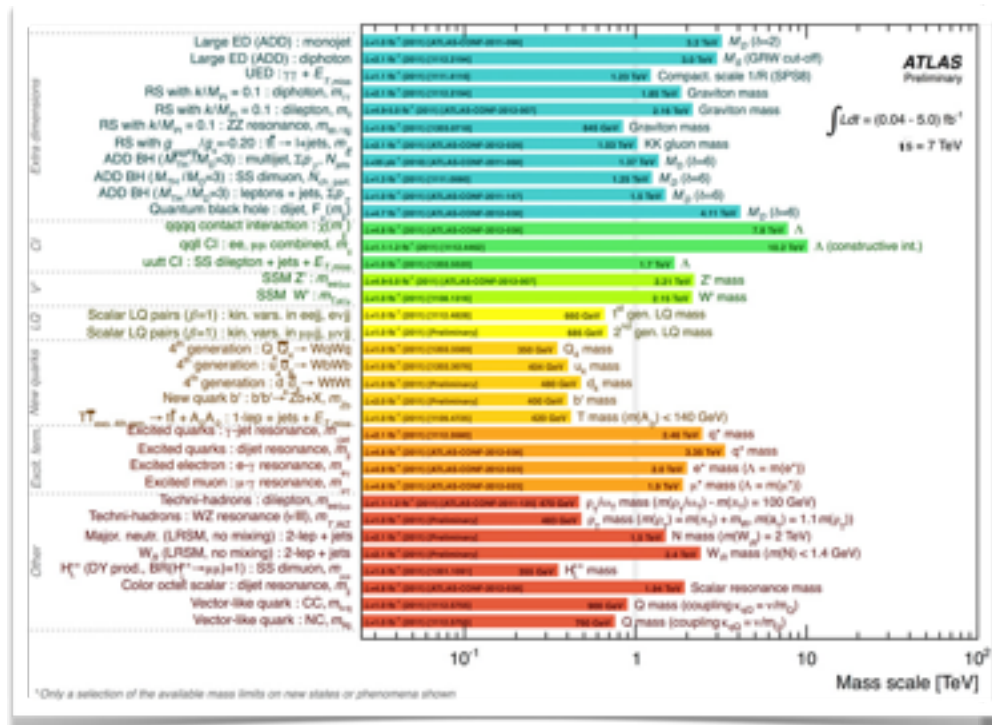
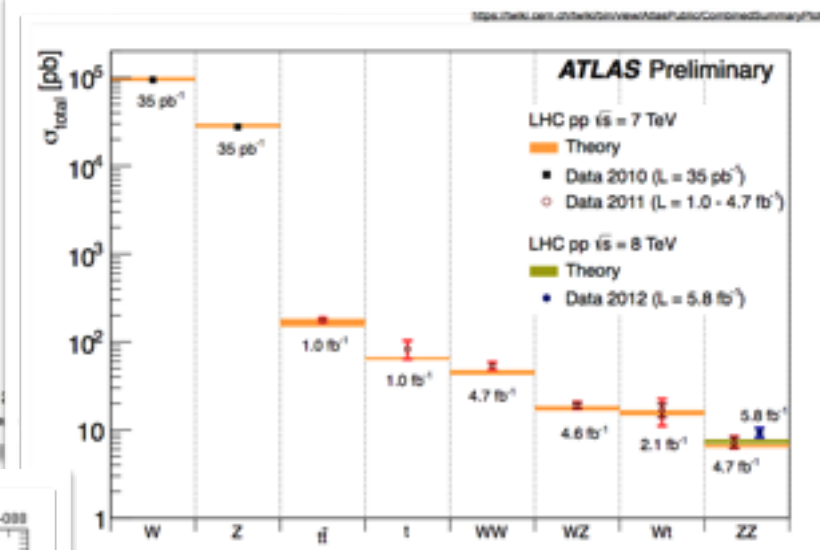
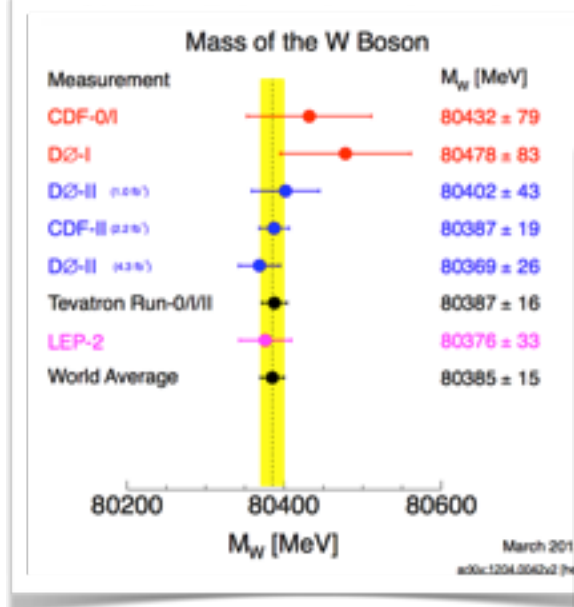
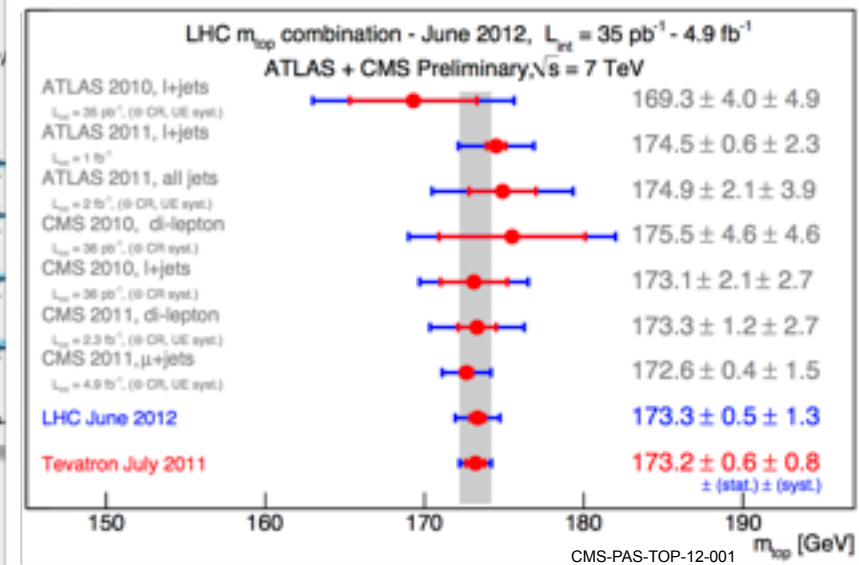
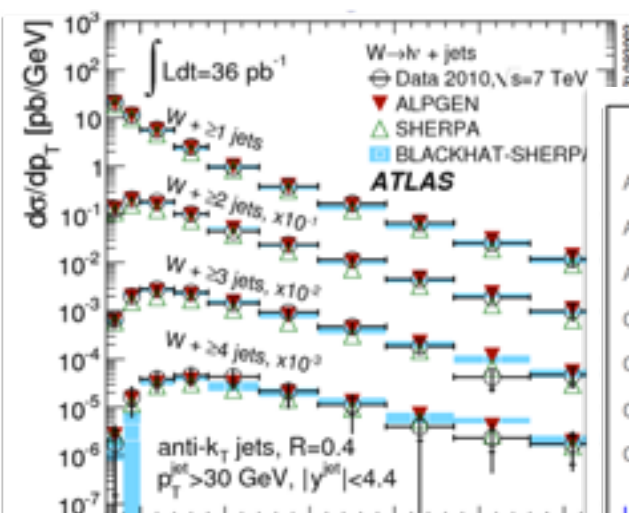
Understanding of Jets

Understanding Top

W mass

Model independent & dependent searches

and more...and more.



Precision

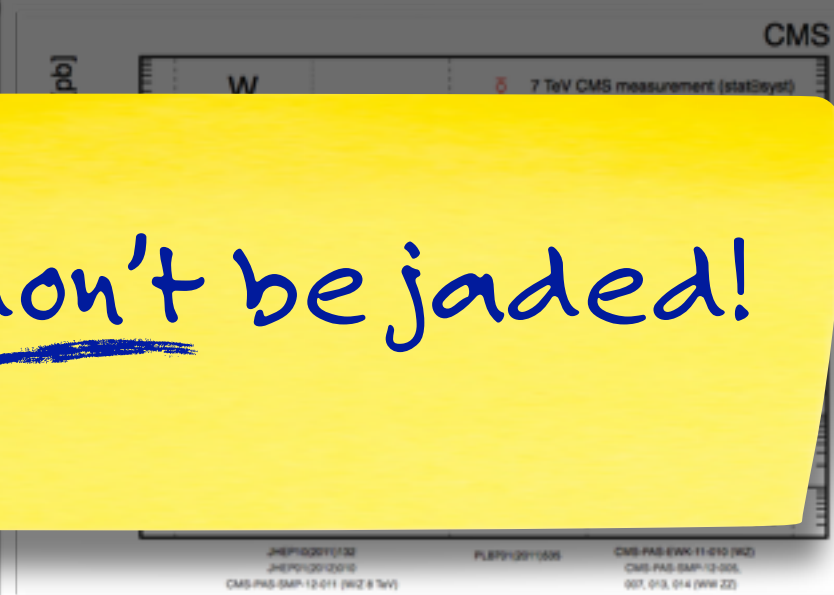
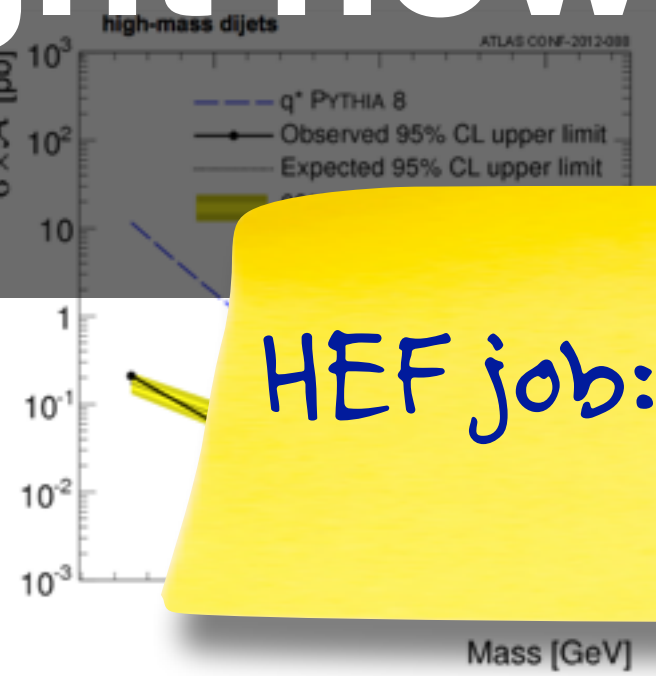
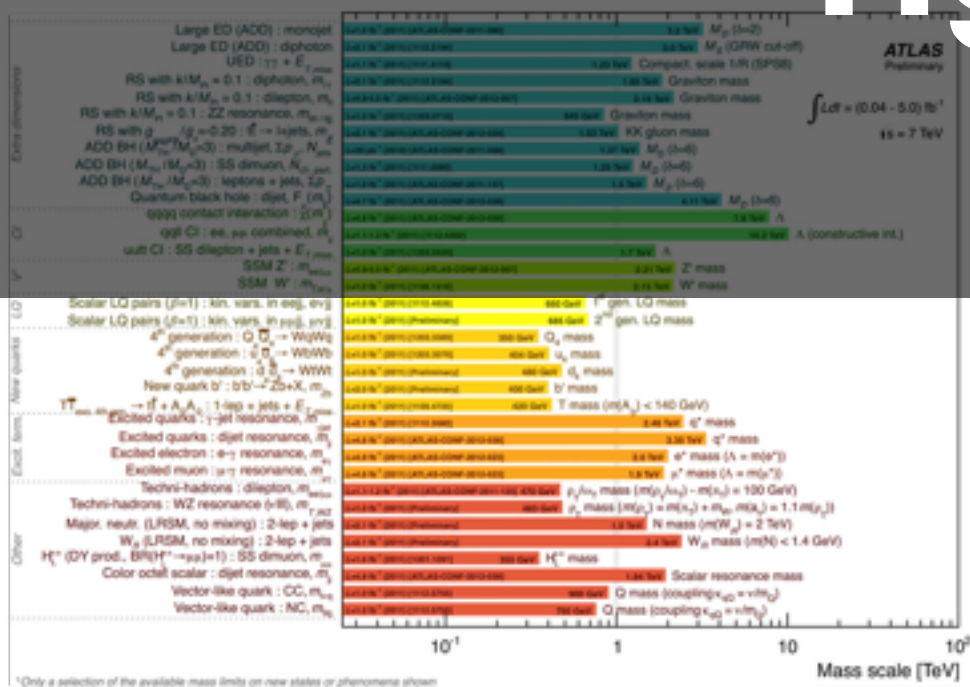
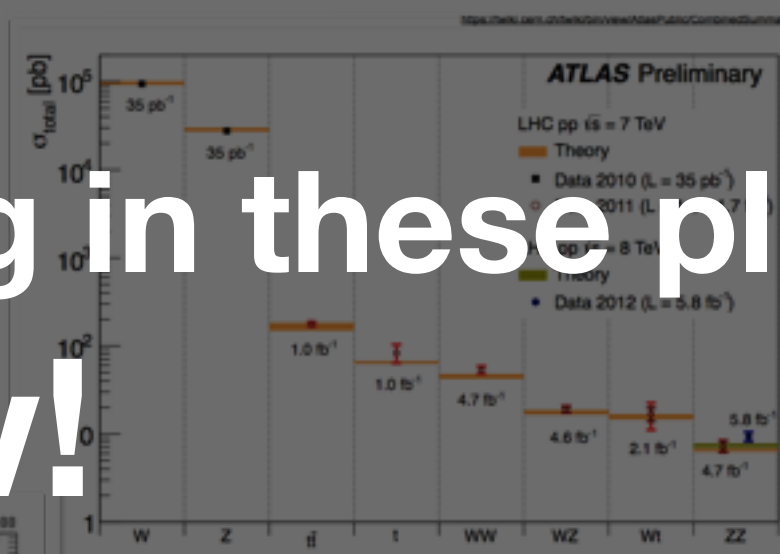
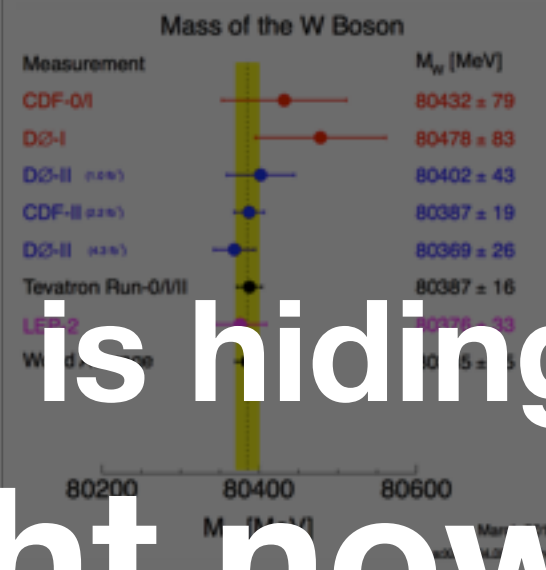
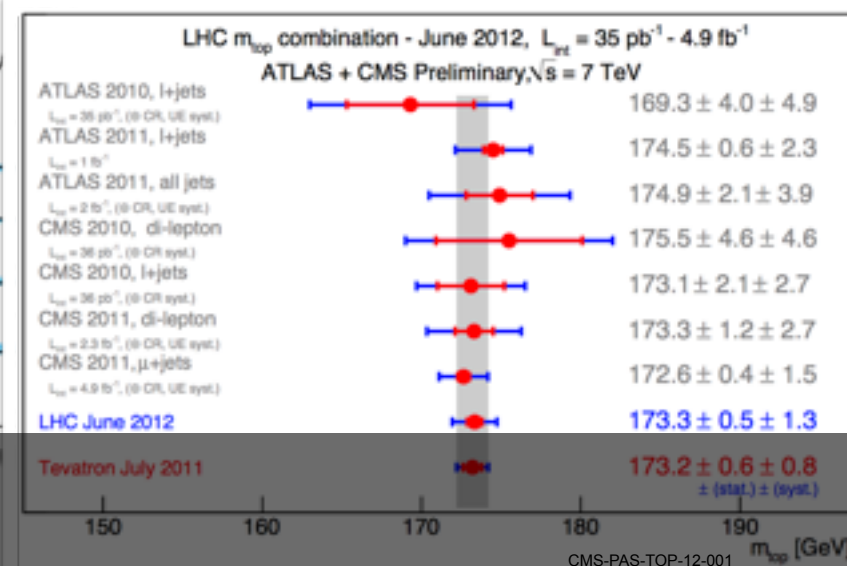
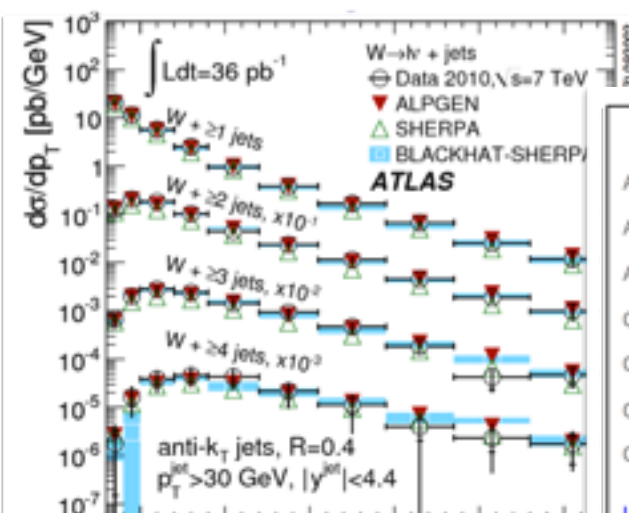
Understanding of Jets

Understanding Top

W mass

Model independent &

The New Physics is hiding in these plots
and more...and more...
right now!



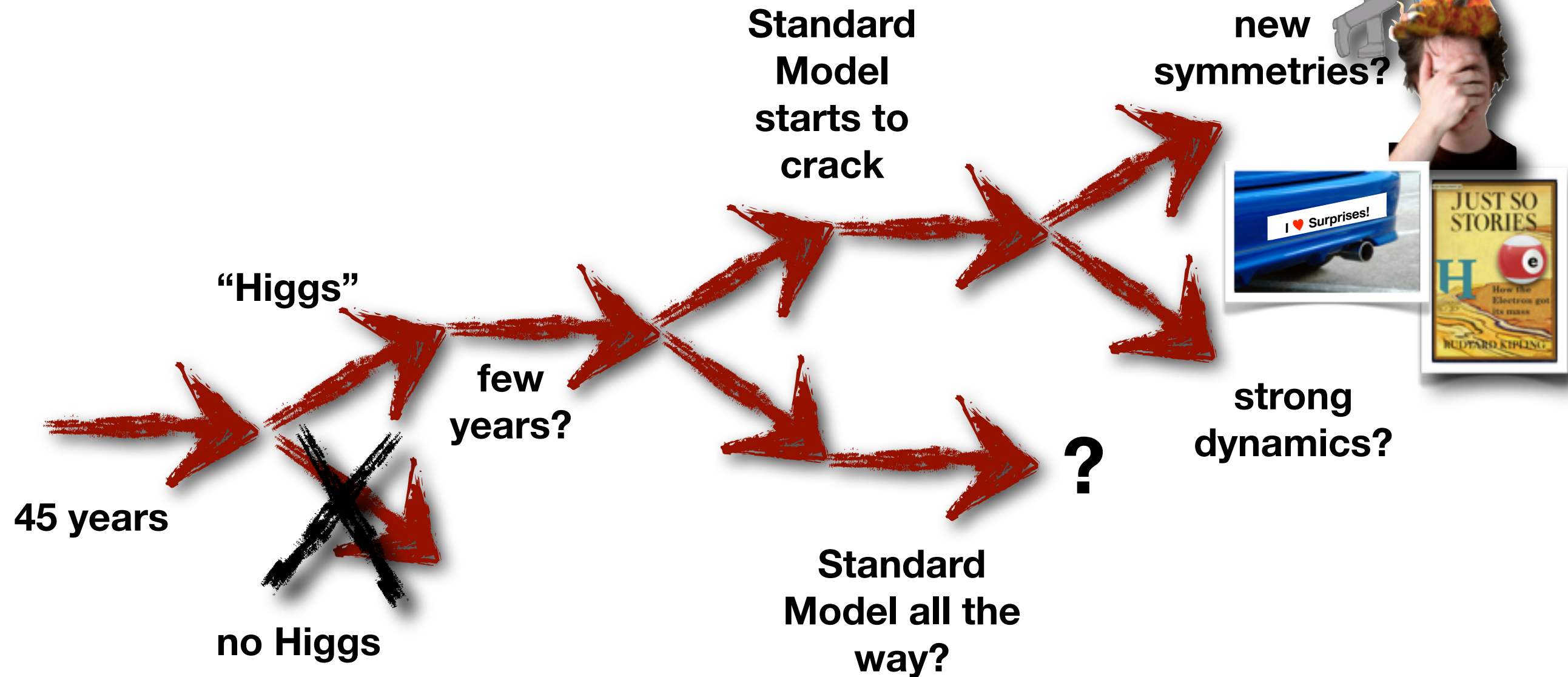
HEF job: don't be jaded!

So, the High Energy Frontier's Jobs:

- 1. Study the Higgs-like state at 125 GeV**
- 2. Full-out on some troublesome questions**
- 3. Write the story that encompasses the SM**
- 4. Be nimble and observant to surprises**



So, it's just getting interesting at the HEF!



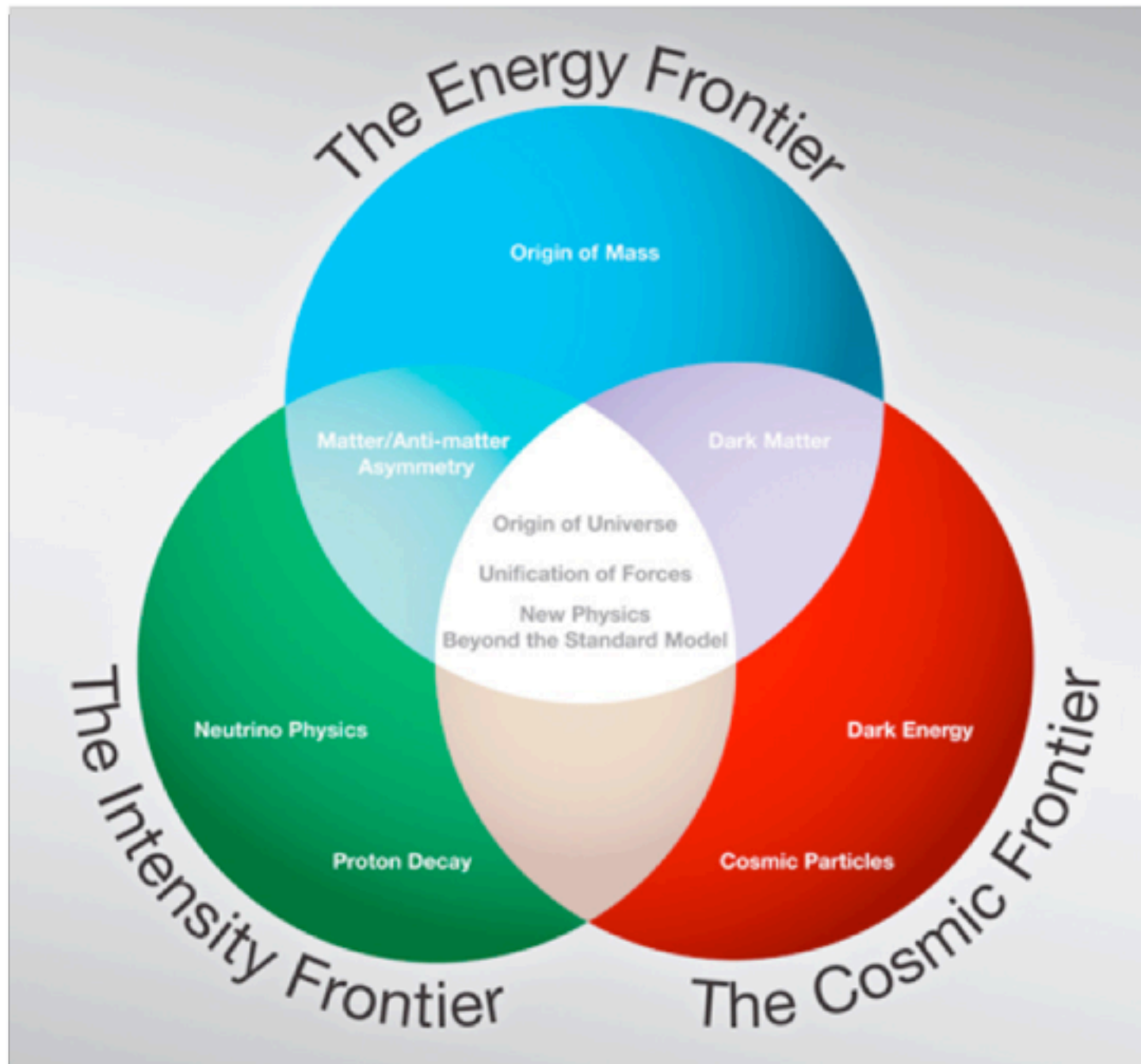
apologies to Matt Strassler

2. High Energy Frontier Study, practicalities

A gift from 2008 P5:

“the Frontier Circles”

and we're organized around them

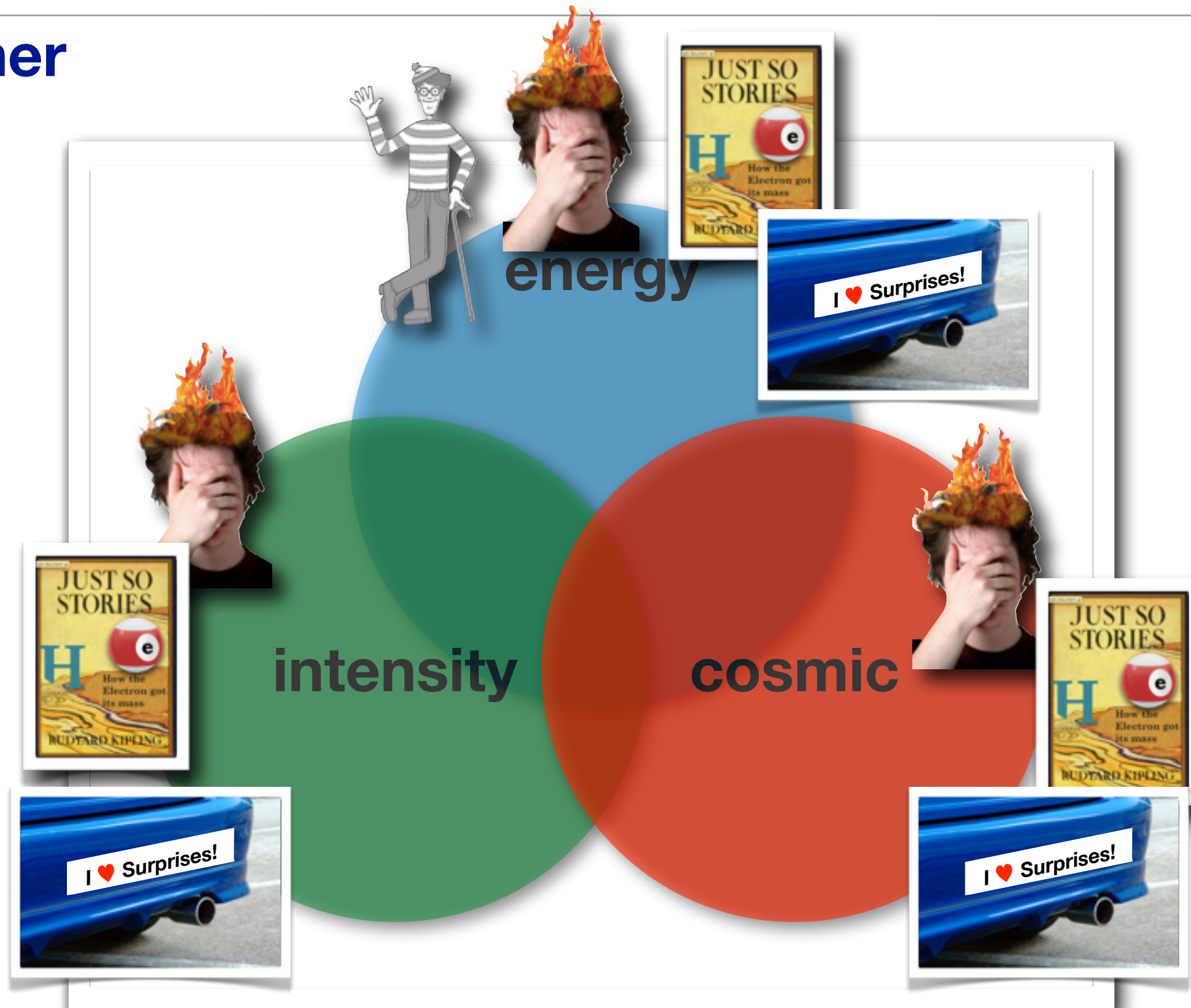


US Particle Physics:
Scientific Opportunities
A Strategic Plan
for the Next Ten Years

Report of the Particle
Physics Project
Prioritization Panel

29 May 2008

All of the Frontiers participate in the 3 jobs
together



what we've done:

Identified terrific subgroup conveners

most have been meeting together for about a month

Created necessary correlations among groups

Decided on technical “connective tissue” groups

Explicit liaisons between HEF and other frontiers

Additional group “infrastructure”

established direct connection with the established collaborations:

“Contacts and consultants”: ATLAS: Paul Tipton; CMS: Jim Olsen; LHCb: Sheldon Stone; ILD: Graham Wilson; SiD: Andy White; CLIC: Mark Thomson; Muon Collider: Ron Lipton

High Energy Frontier working groups

HE1: The Higgs Boson

Jianming Qian (Michigan), Andrei Gritsan (Johns Hopkins), Heather Logan (Carleton), Rick Van Kooten (Indiana), Chris Tully (Princeton), Sally Dawson (BNL)

HE2: Precision Study of Electroweak Interactions

Michael Schmitt (Northwestern), Doreen Wackeroth (Buffalo), Ashutosh Kotwal (Duke)

HE3: Fully Understanding the Top Quark

Robin Erbacher (Davis), Reinhard Schwienhorst (MSU), Kirill Melnikov (Johns Hopkins), Cecilia Gerber (UIC), Kaustubh Agashe (Maryland)

HE4: The Path Beyond the Standard Model—New Particles, Forces, and Dimensions

Daniel Whiteson (Irvine), Liantao Wang (Chicago), Yuri Gershtein (Rutgers), Meenakshi Narain (Brown), Markus Luty (UC Davis)

HE5: Quantum Chromodynamics and the Strong Interactions

Ken Hatakeyama (Baylor), John Campbell (FNAL), Frank Petriello (Northwestern), Joey Huston (MSU)

HE6: Flavor Physics and CP Violation at High Energy

Soeren Prell (ISU), Michele Papucci (LBNL), Marina Artuso (Syracuse)

HEF Goals:

1. In light of circa 2013 results what physics can be achieved before ~2018

...at design specifications with $\int \mathcal{L} dt \sim 100 \text{ fb}^{-1}$)?

2. What are the LHC high luminosity physics goals for

...“Phase 1”: circa 2022 with $\int \mathcal{L} dt$ of approximately 400 fb^{-1}

...“Phase 2”: circa 2030 with $\int \mathcal{L} dt$ of approximately 3000 fb^{-1}

How do the envisioned upgrade paths inform those goals?

Specifically, to what extent is precision Higgs Boson physics possible?

3. Does a Higgs Boson @ $\sim 125 \text{ GeV}/c^2$ call for a “Higgs Factory”?

4. What are the physics cases for accelerators beyond 2025?

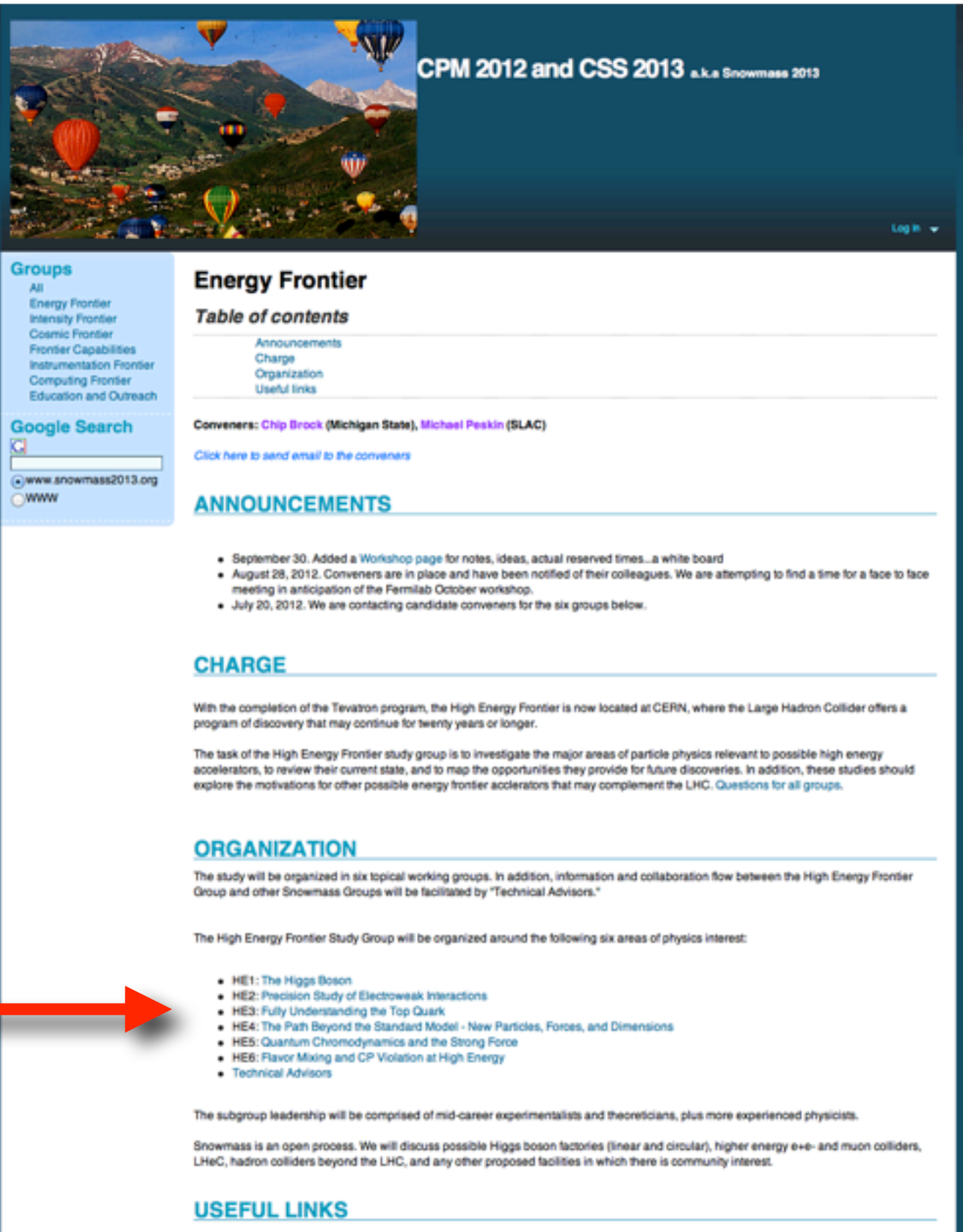
High energy LHC? High energy lepton collider? Lepton-hadron collider? VLHC?

We too have a wiki

<http://www.snowmass2013.org>

increasingly active

find each group's detailed charges



The screenshot shows the Snowmass 2013 website. At the top, there's a banner image of hot air balloons over a mountain range with the text "CPM 2012 and CSS 2013 a.k.a Snowmass 2013". Below the banner, the page is divided into several sections. On the left, there's a "Groups" sidebar with links to "All", "Energy Frontier", "Intensity Frontier", "Cosmic Frontier", "Frontier Capabilities", "Instrumentation Frontier", "Computing Frontier", and "Education and Outreach". Below this is a "Google Search" box with the URL "www.snowmass2013.org" entered. The main content area is titled "Energy Frontier" and includes a "Table of contents" with links to "Announcements", "Charge", "Organization", and "Useful links". Below this, the "Conveners" are listed as "Chip Brock (Michigan State)" and "Michael Peskin (SLAC)", with a link to "Click here to send email to the conveners". The "ANNOUNCEMENTS" section contains three bullet points about recent updates. The "CHARGE" section describes the High Energy Frontier's location at CERN and its goals. The "ORGANIZATION" section details the study group's structure and six areas of physics interest: HE1: The Higgs Boson, HE2: Precision Study of Electroweak Interactions, HE3: Fully Understanding the Top Quark, HE4: The Path Beyond the Standard Model - New Particles, Forces, and Dimensions, HE5: Quantum Chromodynamics and the Strong Force, and HE6: Flavor Mixing and CP Violation at High Energy. The "USEFUL LINKS" section is at the bottom.

CPM 2012 and CSS 2013 a.k.a Snowmass 2013

Log in

Groups

- All
- Energy Frontier
- Intensity Frontier
- Cosmic Frontier
- Frontier Capabilities
- Instrumentation Frontier
- Computing Frontier
- Education and Outreach

Google Search

www.snowmass2013.org

WWW

Energy Frontier

Table of contents

- Announcements
- Charge
- Organization
- Useful links

Conveners: [Chip Brock](#) (Michigan State), [Michael Peskin](#) (SLAC)

[Click here to send email to the conveners](#)

ANNOUNCEMENTS

- September 30. Added a [Workshop](#) page for notes, ideas, actual reserved times...a white board
- August 28, 2012. Conveners are in place and have been notified of their colleagues. We are attempting to find a time for a face to face meeting in anticipation of the Fermilab October workshop.
- July 20, 2012. We are contacting candidate conveners for the six groups below.

CHARGE

With the completion of the Tevatron program, the High Energy Frontier is now located at CERN, where the Large Hadron Collider offers a program of discovery that may continue for twenty years or longer.

The task of the High Energy Frontier study group is to investigate the major areas of particle physics relevant to possible high energy accelerators, to review their current state, and to map the opportunities they provide for future discoveries. In addition, these studies should explore the motivations for other possible energy frontier accelerators that may complement the LHC. [Questions for all groups.](#)

ORGANIZATION

The study will be organized in six topical working groups. In addition, information and collaboration flow between the High Energy Frontier Group and other Snowmass Groups will be facilitated by "Technical Advisors."

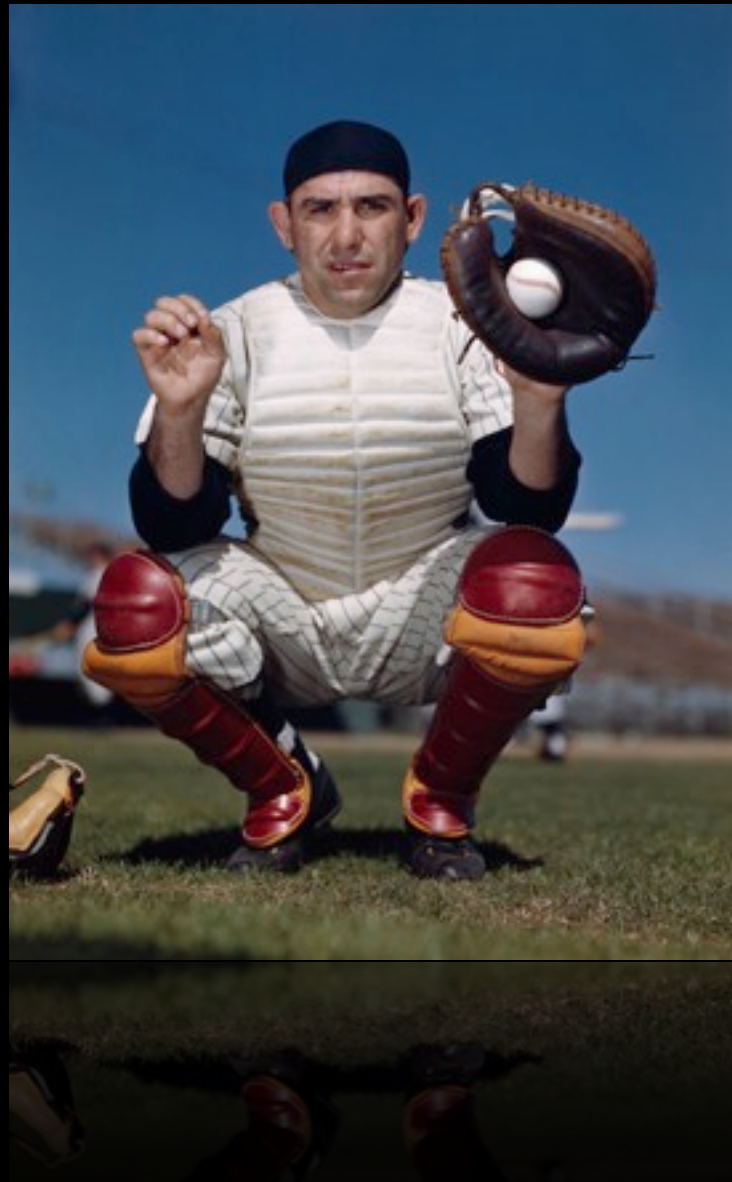
The High Energy Frontier Study Group will be organized around the following six areas of physics interest:

- HE1: The Higgs Boson
- HE2: Precision Study of Electroweak Interactions
- HE3: Fully Understanding the Top Quark
- HE4: The Path Beyond the Standard Model - New Particles, Forces, and Dimensions
- HE5: Quantum Chromodynamics and the Strong Force
- HE6: Flavor Mixing and CP Violation at High Energy
- Technical Advisors

The subgroup leadership will be comprised of mid-career experimentalists and theoreticians, plus more experienced physicists.

Snowmass is an open process. We will discuss possible Higgs boson factories (linear and circular), higher energy e+e- and muon colliders, LHeC, hadron colliders beyond the LHC, and any other proposed facilities in which there is community interest.

USEFUL LINKS



“You can observe a lot
just by watching.”

Candidate scenarios to be addressed by all groups:

- A. The LHC with $E = 14 \text{ TeV}$ and $L = 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ ✓✓✓✓
- B. A luminosity upgraded LHC with: $E_{cm} = 14 \text{ TeV}$, $L = \sim 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ ✓✓✓
- C. An energy upgraded LHC !
- D. $e+e^-$ lepton colliders $E_{cm} < \sim 1 \text{ TeV}$ ✓✓✓
- E. A circular $e+e^-$ collider operating as a Higgs factory. !
- F. $e+e^-$ or gamma-gamma collider $E_{cm} > \sim 1 \text{ TeV}$ ✓✓
- G. A $\mu+\mu^-$ collider. ✓
- H. A lepton-hadron collider. ✓
- I. A VLHC hadron collider with energy well above the LHC energy. ✓

- It is important to point out critical points in energy or luminosity that are essential to realize physics goals.
- For experiments at hadron colliders, a specific question is the effect of the machine environment for high-luminosity running. Do high-luminosity conditions compromise the needed measurements? Are there detector designs or experimental strategies that can ameliorate these problems?

Common template Charge to each HEF Group:

1. Please provide a compact summary of the state of the search for X physics, including information from LEP, the Tevatron, and the LHC.

2. Please address the following goals for X physics in the future:

- ...tailored list of questions/goals follow

3. Please guide your exploration of the above goals with the following scenarios/caveats:

- Evaluate the above goals in the context of Candidate Facilities A-I. (Collaboration with the Facilities Frontier is expected.)
- Are new theoretical or simulation tools (for signal or backgrounds) required in order to achieve the goals?
- What are the detector and computing challenges that the above goals imply? (Collaboration with the Instrumentation and Computing Frontiers is expected.)

an expurgated version

of their charges

Charge to the group,

The Higgs Boson:

- **How will we measure the full phenomenological profile of the Higgs boson?**
- **What level of precision can be achieved at the various proposed accelerators?**
- **What are the unique capabilities of each program?**
- **How will we discover possible additional states in the Higgs sector?**
- **To what extent are properties of the Higgs sector important more generally for fundamental physics?**

Charge to the group,

Precision Study of Electroweak Interactions:

- **What are the most important precision observables that will be studied at proposed accelerators?**
- **What level of precision can be achieved, and what is the importance of these measurements?**
- **How well can we probe the couplings of the W and Z bosons?**
- **What do we hope to learn from these measurements?**

Charge to the group,

Fully Understanding the Top Quark:

- **How well can we measure the top quark mass and width at proposed accelerators?**
- **How well can we measure the couplings of the top quark?**
- **How deeply can we probe for rare decays of the top quark?**
- **How can we use these measurements to search for new physics?**
- **Are there new particles that decay to top? How can we find them?**

Charge to the group,

The Path Beyond the Standard Model:

- **What is the new picture of physics at the TeV scale including the new information from LHC?**
- **Can electroweak symmetry breaking still be "natural"? What does this imply?**
- **What types of new particles might be found at the various proposed accelerators?**
- **Are there more effective strategies to discover Supersymmetry, Composite Higgs, and other proposed models?**
- **How can accelerator experiments help to address the problem of dark matter?**

Charge to the group,

Quantum Chromodynamics and the Strong Interactions:

- **How can we improve the precision of our understanding of the strong interactions in perturbative QCD, in parton distributions, in non-perturbative physics?**
- **How do we incorporate electroweak interactions into precision QCD?**
- **How can QCD concepts such as jet substructure be used as tools for experimental discovery?**

Charge to the group,

Flavor Physics and CP Violation at High Energy:

- **What are the viable models of TeV scale physics that include flavor non-universality and CP violation?**
- **What new particles or new signatures are implied by these theories? How will we discover them?**
- **How can high energy hadron colliders uniquely search for new physics in b and tau decays?**

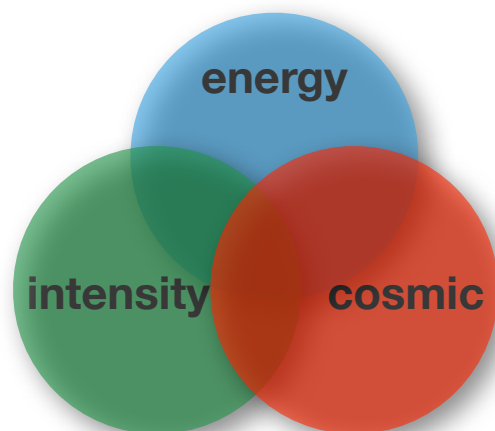
the overlaps

2 kinds of overlaps

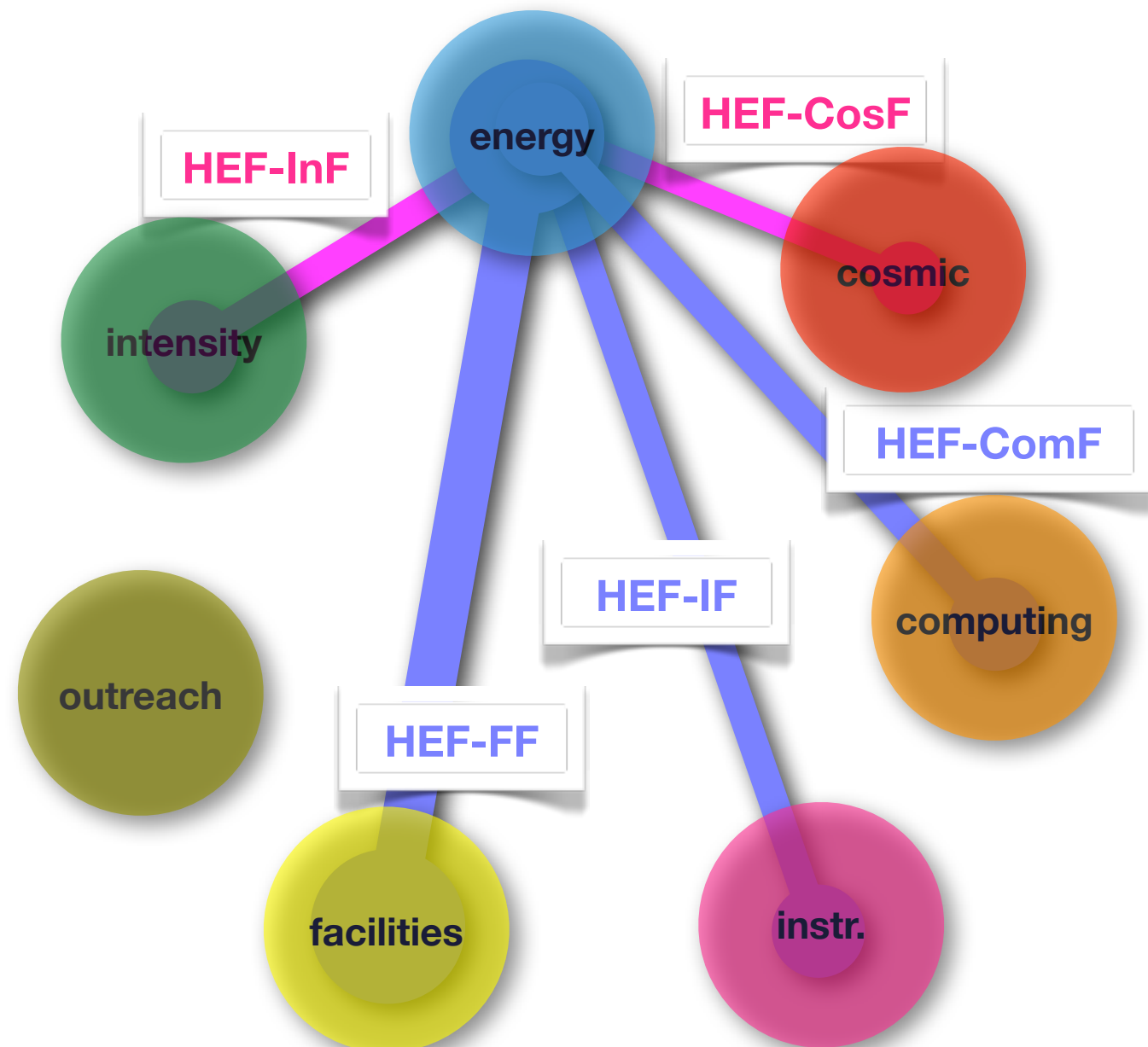
Facilities, Instrumentation, and Computing Frontiers

Other Physics Frontiers groups

This is our sentiment:



This is our organizational reality:



“technical group”

An explicit interface between the HEF physics groups and the FF, IF, and CF groups

Technical Group:

Beate Heinemann (Cal), Tom LeCompte (ANL), Jeff Berryhill (FNAL), Eric Torrence (Oregon),
Tor Raubenheimer (SLAC), Eric Prebys (FNAL)

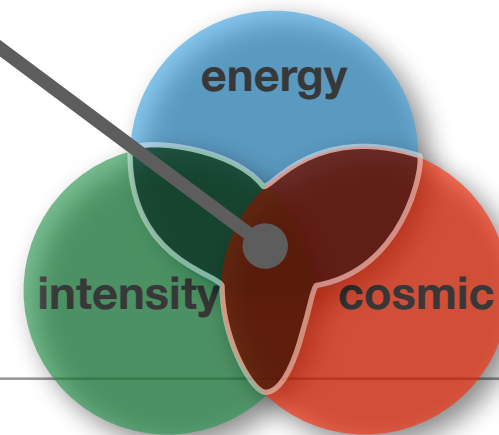
Early in the new year:

Establishing common benchmark parameters for each Candidate Facility
in support of the physics groups

Throughout the spring and workshop:

Liaison with the Facilities, Instrumentation and Computing Frontier Groups

this part!



Physics overlaps

Explicit dual-coverage conveners:

HEF & CF (Dark Matter): Lian-Tao Wang & Konstantin Matchev

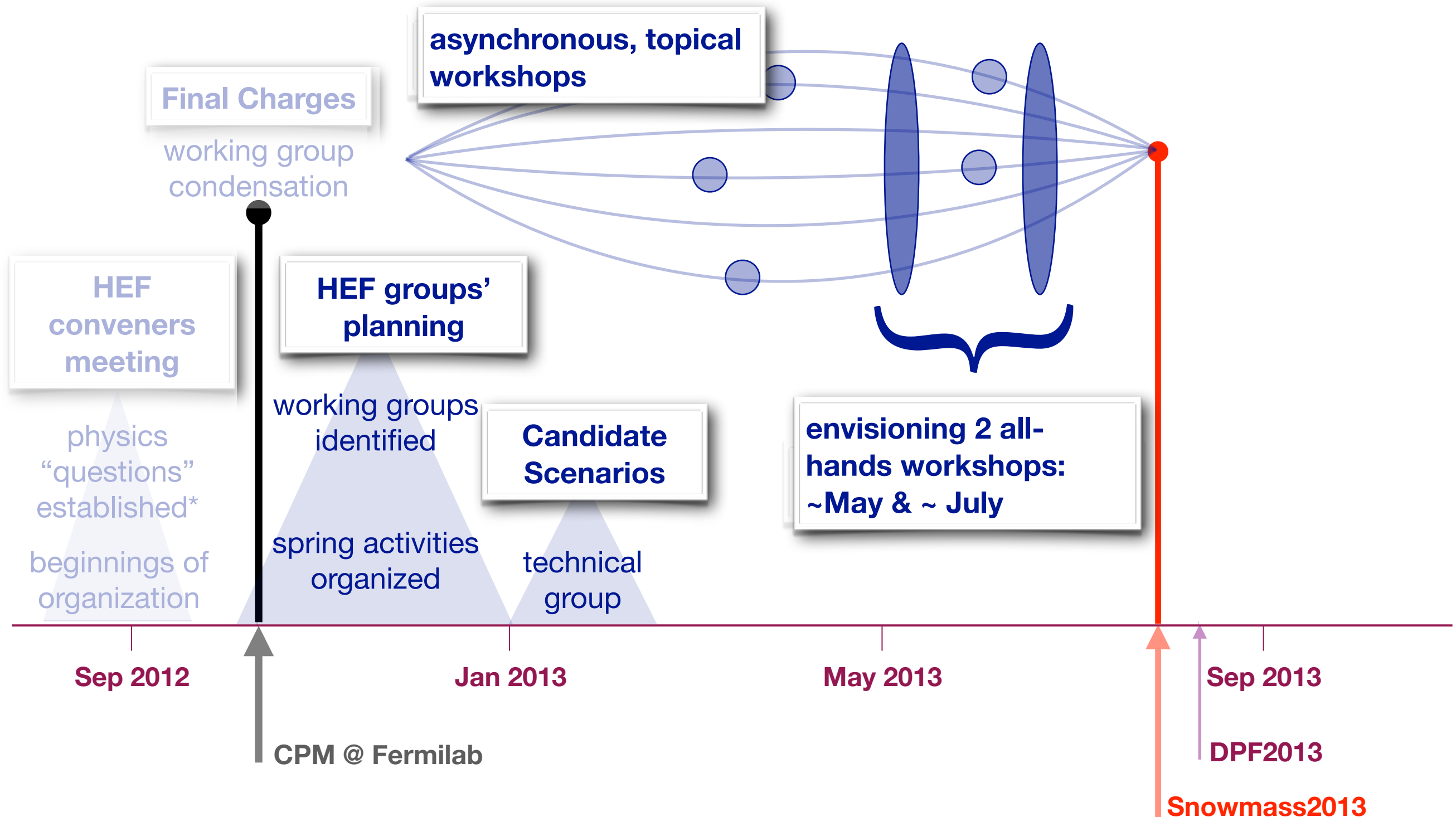
HEF & CF (Baryogenesis): Michele Papucci & Ann Nelson

HEF & HIF (b physics): Michele Papucci & Zoltan Ligeti

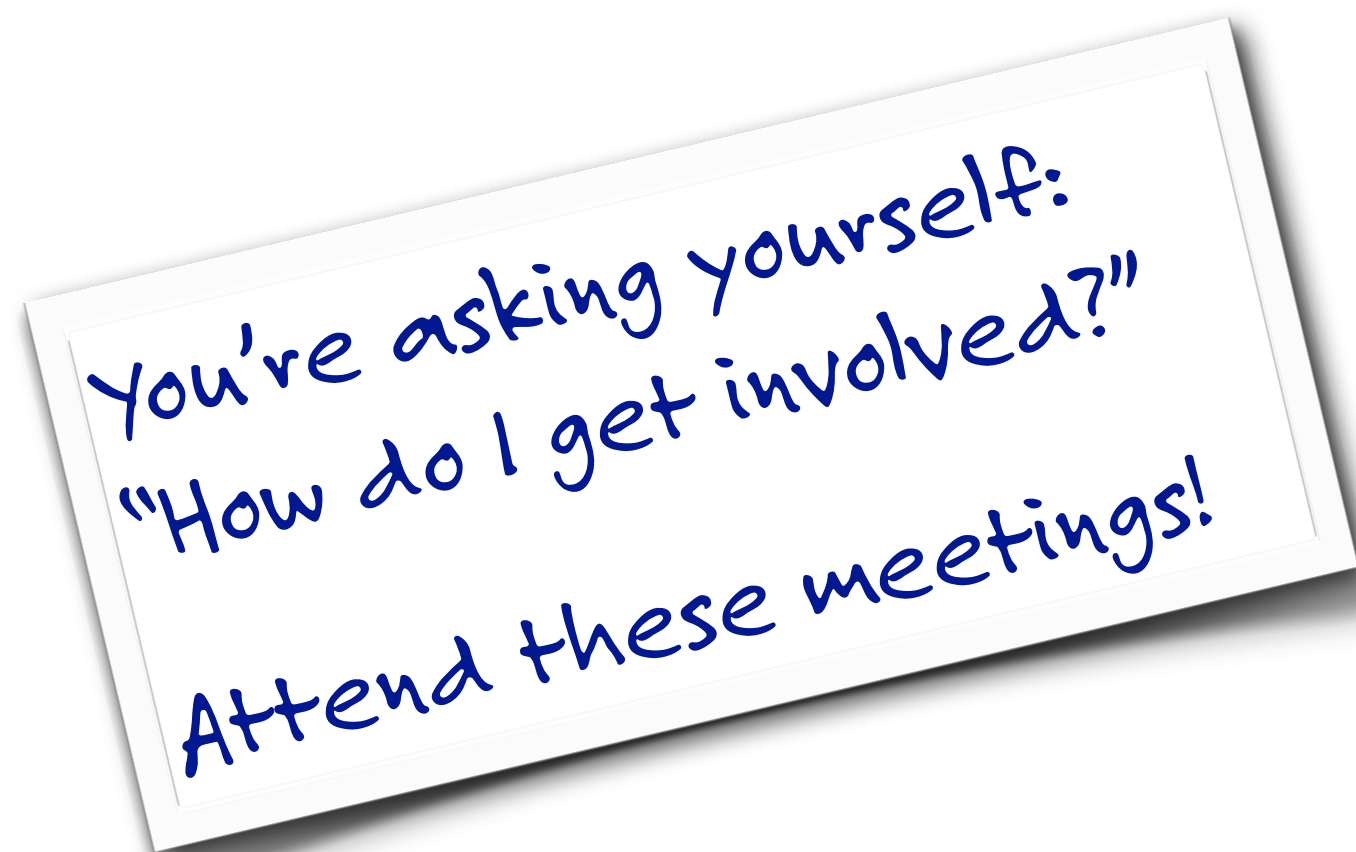
3. What's next for the High Energy Frontier

our to-do list

1. work.



4. This meeting: A full agenda for Friday



HEF Agenda for Friday, October 12th

During the day: The Auditorium

Subgroup Conveners will present

plans, organization, projects for study
orientation to future colliders and challenges for experimentation

During the evening (19:30 - 21:00)

Six parallel working meetings, including some joint meetings

ReadyTalk is available for all meetings.

During the Day: The Auditorium

Friday Morning

S1: 09:30 - 10:30 Landscape of Future Colliders

(joint HEF/Facilities)

Eric Prebys (FNAL): Hadron Colliders (15 + 5)

Mark Palmer (FNAL): Lepton Colliders (15+5)

Eric Torrence (Oregon): Physics Simulation for Hadron and Lepton Colliders (15+5)

S2: 10:45 - 11:45 Higgs / Electroweak

Chris Tully (Princeton): Higgs Physics at Hadron Colliders (15 + 5)

Rick Van Kooten (Indiana): Higgs Physics at Lepton Colliders (15 + 5)

Ashutosh Kotwal (Duke): Electroweak Physics after the Higgs Discovery (15+5)

S3: 12:00 - 13:00 Top / QCD

Joey Huston (Michigan State): Major Issues in QCD (25+5)

Reinhard Schwienhorst (Michigan State): Top quark physics (25+5)

(no break for lunch!)

During the Day: The Auditorium

Friday Afternoon

S4: 13:15 - 14:15 Challenges for Future Experiments

(joint HEF/Instrumentation/Computing)

Ulrich Heintz (Ohio): Detector Challenges for Future Hadron Colliders (15+5)

Andy White (UT Arlington): Detector Challenges for Future Lepton Colliders (15+5)

Ian Fisk (FNAL): Computing Challenges and Opportunities in the Next Decade (15+5)

S5: 14:30 - 15:30 New Particles / Flavor

Yuri Gershtein (Rutgers): What are the options for search strategies; how do we evaluate them? (5)

George Redlinger (BNL): Future of the search for supersymmetry at colliders (15)

Paddy Fox (FNAL): Future of the search for composite Higgs models and related exotic particles at colliders (15)

Michele Papucci (LBNL): Flavor Physics and CP violation at high energy (25)

During the Evening: Parallel Sessions

Friday Evening

19:30 - 21:00 **New Particles, Daniel Whiteson**

WH3NE (THEORY)

Informal discussion of new particle searches: What studies should be done, how do we cooperate between groups, what should the final product be?

19:30 - 21:00 **Flavor, Soeren Prell**

WH3NW (Conjectorium)

Informal discussion of Flavor Physics and CP violation at high energy: What are the important topics to study?



During the Evening: Parallel Sessions

Friday Evening

19:30 - 21:00 **Top Quark, Reinhard Schwienhorst**

WH7W (Racetrack)

- 19:30 - 20:00 Discussion of precision top physics (leaders: Gerber + Melnikov)
- 20:00 - 20:30 Discussion of detector physics involving top (leader: Schweinhorst)
- 20:30 - 21:00 Discussion of new physics involving top (leaders: Erbacher and Agashe)

19:30 - 21:00 **QCD, Joey Huston**

WH10W (WestWing)

- 19:30 - 20:00 Introduction and general overview; connections with other efforts, such as Les Houches (Huston)
- 20:00 - 20:30 Discussion of leading questions and issues related to QCD at present and future colliders
- 20:30 - 21:00 Joint discussion with Electroweak group (leader: Petriello)



During the Evening: Parallel Sessions

Friday Evening

19:30 - 21:00

Higgs, Chris Tully

WH11NE (Sunrise)

19:30 - 21:00 Informal discussion of studies to be done on hadron and lepton collider strategies for Higgs studies

19:30 - 21:00

Electroweak, Michael Schmitt

WH11SE (RoundTable)

19:30 - 19:50 discussion of future electroweak precisions measurements
(leader: Ashutosh Kotwal)

19:50 - 20:10 Discussion of W and Z trilinear and Quartic couplings
(leader: Michael Schmitt)

20:10 - 20:30 Discussion of Electroweak fits including Higgs
(leader: Doreen Wackeroth)

20:30 - 21:00 joint with QCD....go to **WH10W**

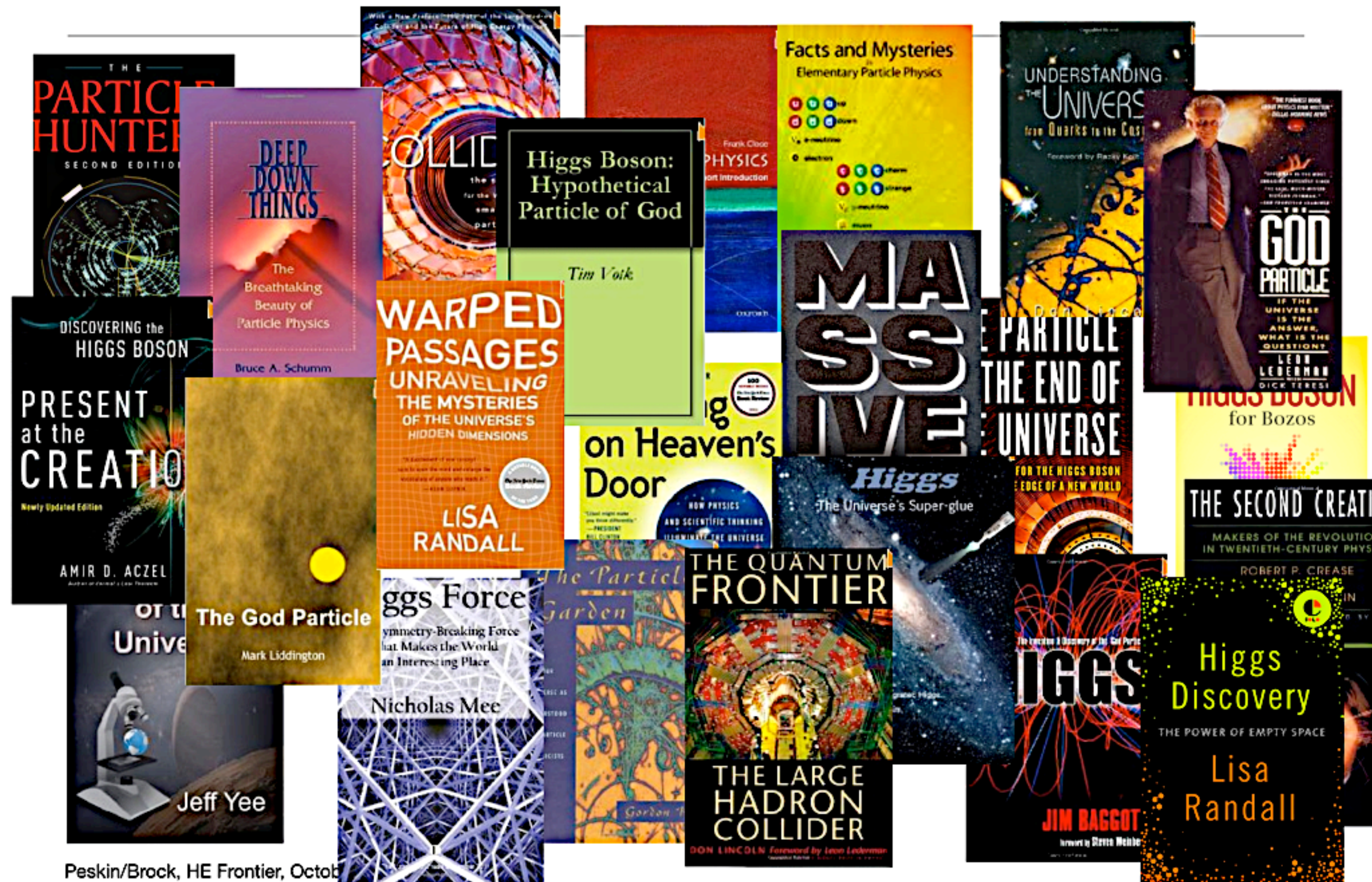


astonishingly

The world followed the Higgs Boson saga

that's a big responsibility

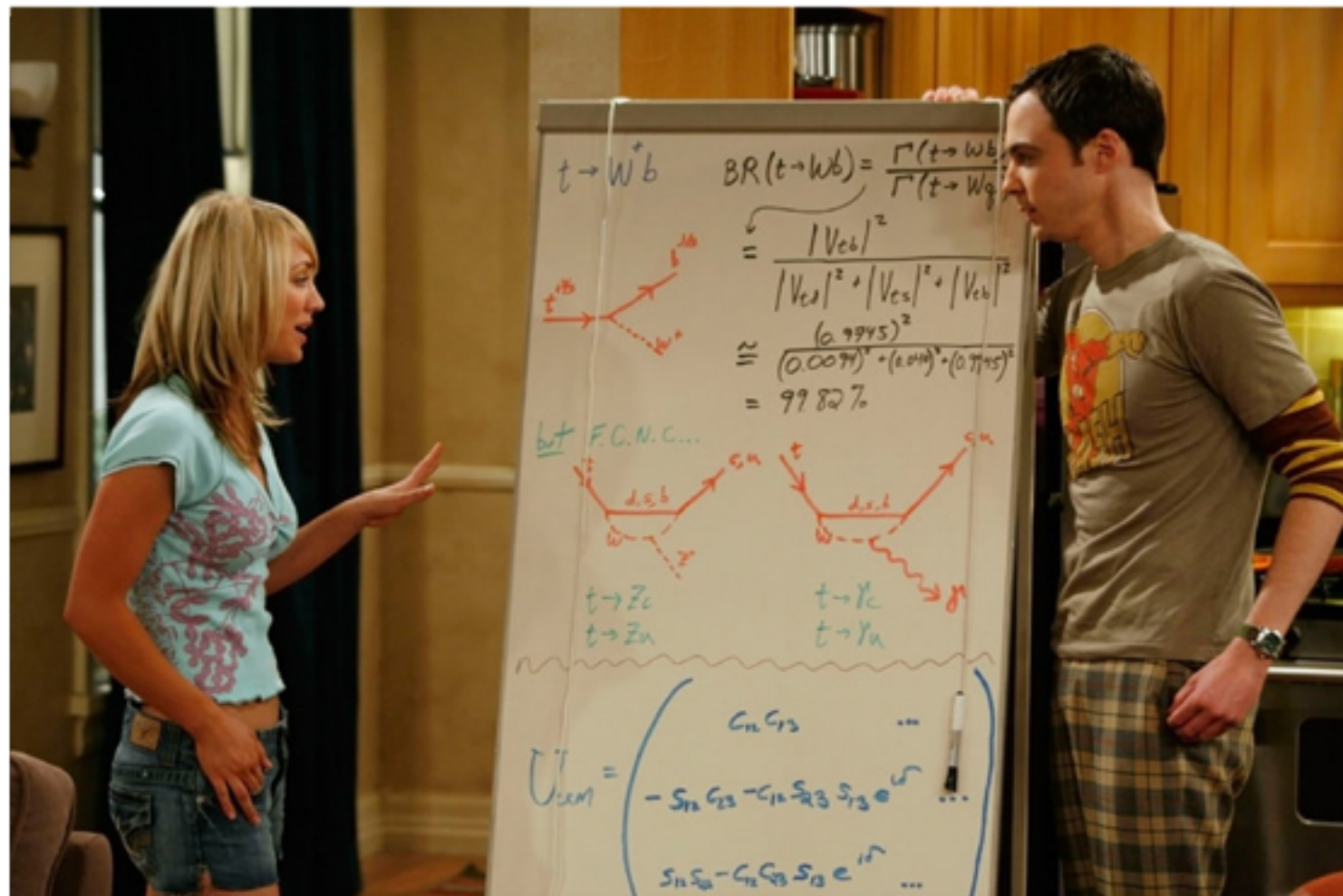
a literature explosion that even astronomers envy

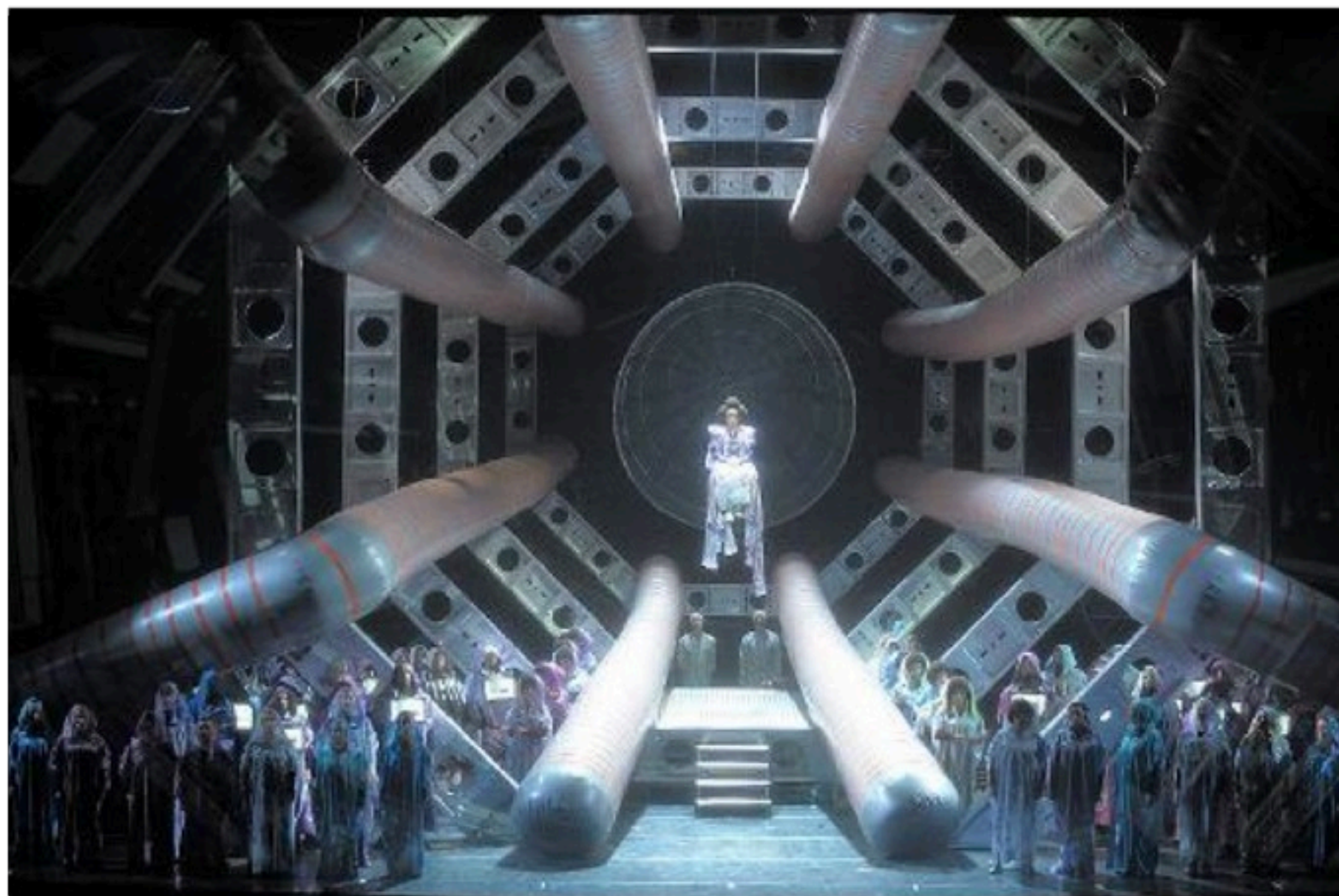


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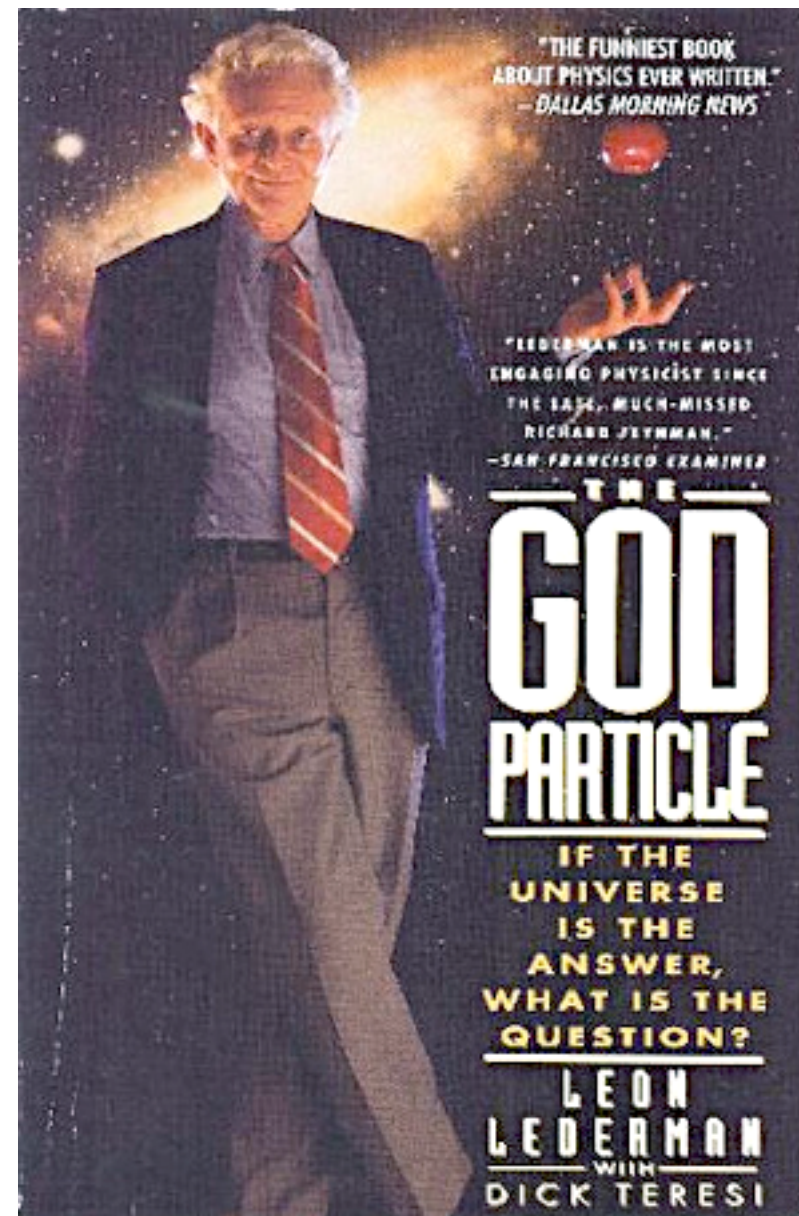


ANGELS & DEMONS
WWW.ENTERTAINMENTWALLPAPER.COM











nonetheless: 6,170,000 Google hits.

Because

the world has followed the Higgs Boson saga

we're in a much different place than in previous times.

Following the post-July physics is going to be fun.

Conclusions

Yes. This Snowmass is a big deal

U.S. participation is essential!

European and Asian participation is essential!

For HEF, the Higgs payoff will still be fresh

Snowmass2013 will guide HEPAP Strategic Planning

Your colleagues need to be involved!



Find us on
Facebook

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<http://www.snowmass2013.org/>

